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COMMITTEE ON THE PEACEFUL USES
OF OUTER SPACE

INTERNATIONAL COOPERATION IN THE PEACEFUL USES OF OUTER SPACE - ACTIVITIES OF MEMBER STATES

Note by the Secretariat

Addendum

The present document contains information provided in replies received from Member States up to 1 April 1992.

CONTENTS

	Page
United States of America	1

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UNITED STATES OF AMERICA

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CONTENTS

Executive Summary

I. INTRODUCTION

II. SPACE FLIGHT

A. Space Shuttle

1. Safety Improvements
2. Advanced Solid Rocket Motor (*ASRM*) Program
3. Extended Duration Orbiter (*EDO*) Program

B. NASA Unmanned Launch Vehicles and Upper Stages Program and Expendable Launch Vehicles (*ELVs*)

C. Flight Systems

1. Tethered Satellite System (*TSS*)
2. Spacelab

D. Advanced Transportation Systems

1. New Launch System (*NLS*)
   a. Personnel Launch System (*PLS*)
   b. Shuttle-C (Cargo) studies
2. National Aerospace Plane (*NASP*)
3. Solid Propulsion Integrity Program

E. Orbital Debris

III. SPACE STATION *FREEDOM*

IV. SPACE SCIENCE AND APPLICATIONS

A. Astrophysics

1. The Great Observatories
   a. Hubble Space Telescope (*HST*)
   b. Gamma Ray Observatory (*GRO*)
   c. Advanced X-Ray Astrophysics Facility (*AXAF*)
   d. Space Infrared Telescope Facility (*SIRTF*)

2. Other Operational Astrophysics Spacecraft
    a. Cosmic Background Explorer (*COBE*)
    b. Roentgen Satellite (*ROSAT*)
3. Explorer Program
    a. Extreme Ultraviolet Explorer (*EUVE*)
    b. X-ray Timing Explorer (*XTE*)
    c. Advanced Composition Explorer (*ACE*)
    d. Far Ultraviolet Spectroscopic Explorer (*FUSE*)
    e. Small Explorer (*SMEX*) Program

B. Solar System Exploration

1. Operational Planetary Spacecraft
    a. *Magellan*
    b. *Galileo*
    c. *Ulysses*
    d. *Voyagers 1 and 2*
    e. *Pioneers 10 and 11*
    f. *Pioneer Venus Orbiter*
2. Future Solar System Exploration
    a. Mars Observer (*MO*)
    b. *CRAF/Cassini*

C. Earth Sciences and Applications

1. Earth Observing System (*EOS*)
2. Earth Probes
    a. Total Ozone Mapping Spectrometer (*TOMS*)
    b. NASA Scatterometer (*NSCAT*)
    c. Tropical Rainfall Measuring Mission (*TRMM*)
3. Near-Term Spacecraft Programs
    a. Upper Atmosphere Research Satellite (*UARS*)
    b. Ocean Topography Experiment (*TOPEX/POSEIDON*)
    c. Laser Geodynamics Satellite-2 (*LAGEOS-2*)
4. On-going Programs
    a. Earth Radiation Budget Experiment (*ERBE*)
    b. Global Tropospheric Experiment (GTE)
    c Boreal Forest Field Study
    d. Airborne Arctic Ozone Experiments
    e. Alaska Synthetic Aperture Radar Facility (*ASF*)
    f. Advanced Sensor Development

D. Space Physics

1. International Solar-Terrestrial Physics (*ISTP*) Program
2. Solar Terrestrial Science Program

3. Suborbital Program

E. Life Sciences

1. Spacelab Life Sciences (*SLS*) Missions
2. Extended Duration Orbiter (*EDO*) Program
3. Centrifuge Facility Program
4. Controlled Ecological Life Support System (*CELSS*)
5. Search for Extraterrestrial Intelligence (*SETI*) Microwave Observing Project
6. Lifesat

F. Microgravity Science and Applications

1. Ground-Based Microgravity Science Research
2. Flight-Based Microgravity Science Research
3. United States Microgravity Laboratory (*USML*) Mission Series
4. International Microgravity Laboratory (*IML*) Missions
5. United States Microgravity Payload (*USMP*) Mission Series
6. Microgravity Science and Applications Program Aboard Space Station Freedom

G. Communications and Informations Systems

1. Mobile Satellite (*MSAT*)
2. Advanced Communications Technology Satellite (*ACTS*)
3. Search and Rescue Satellite (*SARSAT*)
4. Telemedicine

V. THE SPACE EXPLORATION INITIATIVE

VI. SPACE TRACKING OPERATIONS

A. Space Network: Tracking and Data Relay Satellite System (*TDRSS*)

B. Advanced *TDRSS* (*ATDRSS*)

C. Deep Space Network Tracking of *Magellan* and *Galileo*

VII. SPACE RESEARCH TECHNOLOGY

A. Space Research and Technology

1. Transportation
2. Space Station
3. Space Science
4. Exploration
5. Breakthrough

B. Research and Technology Base

C. Civil Space Technology Initiative Program

D. Exploration Technology Program

VIII. SPACE COMMERCE

A. Commercial Development of Space Strategic Planning

B. Commercial Use of the Space Program

C. Commercial Development Payloads

D. Technology Development

E. Cooperative Agreements

F. Technology Utilization Program

G. Small Business Innovation Research Program

IX. INTERNATIONAL SPACE YEAR (*ISY*)

X. SPACE RESEARCH OPPORTUNITIES

A. Announcements of Opportunity

B. Experiments with Foreign Investigators

C. Scientific and Technical Information Exchange

D. Education

E. Visits at NASA and NOAA Facilities

F. International Summer Student Programs

EXECUTIVE SUMMARY

The United States' civil space program was formulated in 1958. Since then, a dozen humans have landed on the Moon and safely returned to Earth, seven of the eight planets have been scrutinized at close range, two robotic spacecraft have landed on Mars, and an unimaginable variety of astronomical and scientific observations have taken place. Closer to Earth, the U.S. space program has helped foster the growth of a comprehensive network of Earth observation satellites that now provide detailed data on weather patterns, ocean currents, and the composition and state of the Earth's surface and atmosphere. In 1990, these efforts and others continued, and the U.S. strengthened its commitment to international cooperation in the peaceful uses of outer space.

In April of 1990, the *Hubble Space Telescope* (HST), a cooperative program with the European Space Agency (ESA), was successfully deployed from the Shuttle *Discovery*. Several weeks later, scientists discovered that the telescope's large mirror was the victim of a tiny spherical aberration which would prevent certain visible light observations. In addition, the spacecraft suffered from a distorting wobble as it passed from darkness into sunlight. The revolutionary nature of this instrument, however, has been preserved, as scientists have learned to compensate for each of these problems. Computer processing has allowed the HST to approach its full capabilities, and unprecedented scientific work in spectroscopy, photometry, astrometry, and ultraviolet wavelength imaging not possible from the ground has now begun in earnest. Through the use of computer image processing, several visible light observations have been made of Orion's nebula and a giant storm on Saturn.

The *Magellan* spacecraft began detailed radar mapping of the Venusian landscape in August of 1990. *Magellan* will conduct the most comprehensive observation of the surface and gravitational features of the planet Venus ever undertaken. During its 243-day (one Venus rotation) primary mission, the spacecraft will map up to 90 percent of the planet with high-resolution imaging radar.

The European Space Agency's *Ulysses* spacecraft, launched in October by the Space Shuttle, is currently on its way to study the poles of the Sun. The *Ulysses* mission is designed to investigate the properties of the heliosphere as a function of solar latitude. *Ulysses* will overfly the high southern solar latitudes in mid-1994 and the northern latitudes in mid-1995. The mission will be completed in late 1995.

Galileo, launched in 1989, has completed the first of two gravitational assist passes, using the gravity of the Earth to speed its journey towards Jupiter. *Galileo* will investigate the structure and physical dynamics of the planet's magnetosphere and will conduct detailed studies of the entire Jovian system, including the planet, its ring, and its four major moons: Io, Ganymede, Callisto, and Europa.

President Bush's Space Exploration Initiative (SEI), as outlined in 1989 and 1990 speeches, calls for an evolutionary approach to expanding human presence and activity into the solar system. In accordance with the program guidelines, NASA has launched an effort to collect the best ideas on how to return to the Moon, establish a permanent manned presence on Earth's satellite, and continue on to Mars. Towards this end, NASA contacted hundreds of public and private sources in industry and academia. Former astronaut Tom Stafford was named to head the group which will analyze the submittals and report their findings in 1991.

Despite a stand-down of five months due to hydrogen leaks, six successful Shuttle missions were flown in 1990, including three in the final three months of the year, the most efficient turn-around time since 1985. Two dedicated Department of Defense payloads, deployment of the SYNCOM IV communication satellite, retrieval of the *Long Duration Exposure Facility* (LDEF), the *Hubble* and *Ulysses* deployments, and the ASTRO-1 observatory mission comprised the 1990 flight manifest. The fact that NASA was able to accomplish this despite the hydrogen leaks is proof that the agency's new safety procedures are having the desired effect: increasing mission safety and mission performance.

NASA also continued its efforts closer to the Earth: approval was received from Congress to begin the *Earth Observing System* (EOS), a series of satellites that will use the perspective from space to analyze the Earth as a global environmental system beginning in 1998. Ozone depletion studies also continued, and NASA has signed an agreement with the Soviet Union to include a Total Ozone Mapping Spectrometer aboard a Soviet satellite in 1991.

The Space Station *Freedom* program was restructured in 1990, so as to be smaller, lighter, and easier to assemble and maintain. These changes add up to a $6 billion savings in development costs over the next five years, while still providing an international space facility devoted to the advancement of life and materials sciences, earth observation, and space exploration.

Finally, NASA has reaffirmed its commitment to effective education in the United States, especially in the fields of mathematics, science, and engineering. In 1990, astronauts aboard the Space Shuttle presented the first live school lesson from space, while, as a result of NASA's Space Exposed Experiment Developed for Students (SEEDS), over 4 million student scientists have planted gardens using tomato seeds flown in space. Results of the students' work will be compiled and analyzed in 1991.

I. INTRODUCTION

The National Aeronautics and Space Act of 1958, as amended, governs United States civil programs and activities designed to support research and development in the exploration of outer space. This Act designates the National Aeronautics and Space Administration (NASA) as the principal civilian agency responsible for the direction and implementation of U.S. aeronautical and space research programs and associated activities.

NASA Headquarters, located in Washington, D.C., plans, coordinates, and administers NASA programs. The Space Science and Space Applications Boards of the National Academy of Sciences, along with the NASA Advisory Council and a number of more specialized panels periodically provide guidance and recommendations to NASA. The actual research and development activities take place at the eight NASA field centers.

In order to bring a greater degree of coherence and continuity to the U.S. effort to explore, study and develop space, President Bush has established the National Space Council under the chairmanship of Vice President Dan Quayle. The role of the National Space Council is to coordinate U.S. civil, military and commercial efforts in space. The Council, as such, works in close cooperation with NASA.

NASA is required by law to conduct its activities so as to contribute to the ideal of international cooperation. Since its inception in 1958, NASA has developed an extensive program of international cooperation involving more than 130 nations and varied international organizations. These international projects are planned and coordinated by the International Relations Division of NASA Headquarters.

Other U.S. Government agencies involved in providing support for the U.S. civil space program include the Department of Commerce's National Oceanic and Atmospheric Administration (NOAA), and the Departments of Defense, Energy, State, and Transportation. In addition, NASA frequently assists the U.S. Agency for International Development (USAID) and cooperates with private U.S. firms in space-related activities.

The National Oceanic and Atmospheric Administration's National Environmental Satellite, Data, and Information Service (NESDIS) manages U.S. civil Earth-observing satellite systems, as well as global data bases for meteorology, oceanography, solid-earth geophysics, and solar-terrestrial sciences. In utilizing these sources, NOAA develops and provides environmental data and information critical to effective weather forecasting, energy development, global distribution of food and

medical supplies, and the prudent, efficient development and management of natural resources.

II. SPACE FLIGHT

Assured access to space sufficient to achieve all U.S. space goals is a key element of national space policy. Current U.S. space transportation policy directs national efforts to achieve and maintain safe and reliable access to, transportation in, and return from space.

The U.S. space transportation capability is based on a "mixed fleet" concept, consisting of the Space Shuttle, unmanned expendable launch vehicles (ELV's), and in-space transportation systems, and involving both the public and the private sectors. The development of an effective and reliable "mixed fleet" of space transportation systems provides a resilient and flexible national capability now and into the foreseeable future.

A. SPACE SHUTTLE

The Shuttle fleet is used to support selected research and development, as well as those critical programs requiring a manned presence or other unique Shuttle capabilities. In 1990, six highly successful Space Shuttle missions confirmed the U.S. commitment to a robust space presence. Since the *Challenger* accident, NASA has gone to great lengths to insure mission safety. In fact, the final three launches of the year took place in the last three months - the quickest turnaround since 1985. Efforts at improving safety have paid off, with opportunities for more frequent and successful missions.

Columbia (STS-32) began the year with a 9 January launch. Its duties included placing a communications satellite into geosynchronous orbit, further filming of the Earth through the IMAX wide lens, and retrieval of the *Long Duration Exposure Facility* (LDEF). The latter had been orbiting the Earth for nearly six years in order to measure the effects of atomic oxygen, space radiation, micrometeoroids, man-made debris, vacuum, and other space-related phenomena on more than 10,000 test specimens from many countries. LDEF will prove to be an invaluable source of data on the characteristics of the space environment, and its potential impact on materials to be used in future spacecraft.

Atlantis and *Discovery* continued these successes with February and April missions (STS-36 and STS-31). The latter mission is particularly noteworthy in that it involved the placing of the *Hubble Space Telescope* (HST) into orbit. HST has begun to revolutionize thought in the fields of both astronomy and astrophysics, and to

provide the international community with a wealth of observed data at a level of detail never before possible.

Shuttle launches were interrupted for five months after hydrogen leaks were detected on *Columbia* and *Atlantis* during external tank loading operations. NASA's improved safety techniques allowed early detection of the problem, and facilitated a rapid return to flight.

Only six months later, *Discovery* flew again (STS-41). This mission launched the *Ulysses* spacecraft towards the Sun. *Ulysses*, a joint project between NASA and the European Space Agency (ESA), will investigate the properties of the heliosphere.

After a classified *Atlantis* mission (STS-38), *Columbia* closed out the year as she had started it - with a flawless flight. In December of 1990, the astronauts of *Columbia* successfully transported the Astrophysics Observatory (ASTRO-1), secured to two Spacelab pallets, into orbit. ASTRO-1, a reusable system, is a carefully selected set of telescopes and instruments uniquely designed to address specific questions in ultraviolet and X-ray astronomy. The use of these instruments is directly supported by Spacelab equipment provided by ESA. In spite of difficulties with the pointing computer for ASTRO-1, NASA was able to successfully view approximately 60% of the original targets.

NASA's current flight manifest includes seven Shuttle missions for 1991, and a total of twenty-seven over the next three years.

A.1. Safety Improvements

Shuttle capability and safety enhancement activities continued in 1990. Since the *Challenger* accident, numerous improvements have been made to the orbiter fleet, including a new emergency crew egress system, enhanced landing and deceleration systems, and the systematic utilization of new and comprehensive safety checks.

Shuttle launches were interrupted for a five month period in 1990, as both *Atlantis* and *Columbia* showed signs of hydrogen leakage. Utilizing improved safety practices, NASA engineers isolated these leaks as being in the seals associated with the seventeen-inch disconnect areas. In accordance with current policy, these areas were promptly replaced. A separate leak in *Columbia*, however, remained elusive. A special team isolated this problem to a seal in the prevalve of the main propulsion system which had been damaged during installation after *Columbia's* January mission. Subsequent tanking tests verified that the problems with *Columbia* and *Atlantis* had been resolved. NASA's enhanced safety requirements ultimately identified, isolated, and corrected the problem without a major impact on the flight performance of the Shuttle fleet.

A.2. Advanced Solid Rocket Motor (ASRM) Program

The ASRM program will develop a replacement for the Shuttle's current solid rocket boosters by the mid-1990's. The new Shuttle motors will provide improved safety, reliability, and performance well into the next century. The ASRM design aims to achieve a 12,000 lb. improvement in the Shuttle's payload lift capability. This increased capability will, in turn, contribute to an overall reduction in transportation costs while effectively supporting Space Station *Freedom* and other important projects.

A.3. Extended Duration Orbiter (EDO) Program

The Extended Duration Orbiter (EDO) concept is a result of a desire to enhance the scientific return from Shuttle flights by increasing on-orbit time from seven days to a sixteen-day capability. The EDO concept is a set of modifications to the existing orbiters fleet. The EDO process will lengthen valuable on-orbit time not only for the conduct of science, but also for the maintenance and repair of orbiting spacecraft, and will also enable the accumulation of extended flight experience. In order to allow for the increased time on orbit, EDO will employ a cryogenic pallet, an upgraded waste management system, an enhanced regenerative carbon dioxide system, and improved crew accommodations.

Modification of one Shuttle, *Columbia*, for the EDO capability will be completed by the end of 1991. NASA's newest Shuttle, *Endeavour*, was designed to possess the capability for full EDO modification, and is scheduled for its maiden flight in May of 1992.

B. NASA UNMANNED LAUNCH VEHICLES AND UPPER STAGES PROGRAM AND EXPENDABLE LAUNCH VEHICLES (ELV's)

ELV's are a reliable, proven means of space transportation. Through implementation of the mixed fleet approach, along with measures designed to foster the development of a U.S. commercial space launch industry, substantial changes have taken place within the NASA Unmanned Launch Vehicles and Upper Stages program over the past five years.

In accordance with National Space Transportation guidelines and existing legislation, U.S. civil government agencies contract for necessary ELV launch services directly from the private sector. The U.S. Government itself fully endorses and facilitates the commercialization of ELV's, while simultaneously encouraging international free market competition.

In 1990 there were six U.S. commercial ELV launches: four successful Delta II launches; and two Titan III launches, one of which was a failure. NASA, for its part, conducted three successful ELV launches in 1990. In May, a NASA Scout vehicle, pulled out of inventory, lofted a U.S. Navy payload into orbit. Later, in June, a U.S. Air Force Delta II launched the *Roentgen Satellite* (ROSAT), a cooperative mission with Germany and the United Kingdom, into orbit. Finally, in July, a commercial Atlas I vehicle launched the *Combined Release and Radiation Effects Satellite* (CRRES) into orbit. This was the first NASA mission to employ launch services procured directly from the private sector.

NASA currently plans four ELV missions in 1991, and a total of forty-one missions over the next eight years. These launches will take place on a combination of NASA, United States Air Force, and commercial vehicles. In 1990, NASA awarded launch contracts in competitive procurement for four firm and twelve optional missions over the next five years. In July of 1990, NASA submitted to Congress a proposed ELV Technology Plan which, if implemented to its logical conclusions, will enhance the performance and reliability of existing ELV's while lowering launch costs. By utilizing commercial launch services and pursuing launch technology advances, NASA will help assure access to space while fostering the growth of the domestic launch industry as a key player in the commercialization of space.

C. FLIGHT SYSTEMS

C.1. Tethered Satellite System (TSS)

The TSS is a cooperative program between NASA and the Italian space agency, *Agenzia Spaziale Italiana* (ASI), designed to conduct electrodynamic atmospheric missions in regions of space that are difficult to reach. The U.S. Space Shuttle will act as the base from which the satellite system is deployed by means of a ten-mile long tether (the "fishing reel"). While NASA is responsible for the development of the tether deployer, as well as overall systems integration, ASI is building the spherical (1.6 meter diameter) satellite that will be attached to the tether. Both countries are sharing development of the scientific instruments.

The TSS arrived at Kennedy Space Center in November of 1990 for final testing and preparation for launch on STS-46 in early 1992. This first mission (TSS-1) will employ a 20 kilometer conductive tether to study the generation of an electric current along the cord as it cuts across the earth's magnetic fields. Further experiments will deal with the effects that variations in the current have on the surrounding space plasma.

C.2. Spacelab

Designed as a scientific observatory and laboratory facility carried to and from orbit in the Shuttle's payload bay, Spacelab provides an on-orbit capability for manned interactive science. The Spacelab facility was developed jointly with ESA to serve as an integral component of the Space Shuttle system. The Europeans developed and built the pressurized lab module, an unpressurized platform pallet and igloo systems, and an instrument orientation system. NASA has developed a new pallet system to allow for mixed cargo arrangements.

Spacelab flights resumed in 1990, beginning with STS-35 and the first flight of ASTRO-1. In all, over 21 Spacelab missions, ten of which will employ the pressurized module, are planned through 1996.

Continuing the tradition of international participation in the Spacelab program, nearly all of the flights scheduled for 1990 and 1991 are multinational in nature. The Spacelab Life Sciences mission (SLS-1), scheduled for launch aboard *Columbia* in May of 1991, will be the first Spacelab mission dedicated solely to the life sciences. The SLS series of missions was proposed by a team of international investigators, including Swiss, Australian, and American life scientists.

Other international Spacelab missions scheduled for the 1990-1993 time frame include:

- the International Microgravity Laboratory (IML-1), composed of facilities developed by ESA, the French National Center for Space Studies (CNES), the German Aerospace Research Establishment (DLR), the National Space Development Agency of Japan (NASDA), and the Canadian Space Agency

- Spacelab-J, sponsored by NASA and NASDA

- German Spacelab D-2, the follow-up to the 1985 Spacelab D-1 mission, including some cooperative experiments between NASA and the DLR

D. ADVANCED TRANSPORTATION SYSTEMS

NASA conducts concept feasibility and selected systems definition, preliminary design studies, and related advanced development on a continual basis. The objective is to provide the technical and programmatic data necessary to effectively identify evolving space transportation system requirements and to evaluate new

space transportation initiatives. This requires the conceptual definition of future space transportation systems architecture and the required specific elements.

D.1. New Launch System (NLS)

The present Space Shuttle orbiter fleet will eventually near the end of its operational lifetime. Consideration of the next manned transportation system has consequently become appropriate. The broad goals for any such transportation system are to meet payload requirements, improve cost effectiveness, and increase system reliability and performance margins. NLS builds on the previous concept of an Advanced Launch System (ALS), and is aimed at providing a family of launch vehicles capable of lifting payloads from 20,000 pounds to 300,000 pounds into orbit. NASA is currently examining three programs that fall under the auspices of NLS:

- Shuttle Evolution/Shuttle-C
- Personnel Launch System (PLS)
- Advanced Manned Launch System (AMLS)

D.1.a. Personnel Launch System (PLS)

A new system such as PLS or AMLS would offer significantly improved capabilities and future potential, but would require ten years or more to build at considerable cost. Evolving the current system would offer more timely and affordable improvements, but would be limited in scope to the potential of the Space Shuttle design specifications envelope.

In 1990, the advanced programs activity in support of the evolving and future space transportation capability focused primarily on the area of a PLS. As there are only a limited number of Shuttles to support the long-term operations of Space Station *Freedom* and future exploratory missions, a dedicated personnel vehicle could serve to effectively complement Shuttle services. Marshall Spaceflight Center is currently designing the PLS launch vehicle. The vehicle will have a launch capability at least equal to that of a Titan IV. Kennedy Space Center is furnishing vehicle processing and launch systems expertise, while Johnson Space Center and Langley Research Center have both prepared designs for the personnel carrier unit itself. In the overall course of the design study, spacecraft shapes ranging from simple capsules to winged gliders will be considered.

D.1.b. Shuttle-C (Cargo) Studies

In 1990, NASA also continued definition studies of an unmanned version of the Space Shuttle, termed Shuttle-C (Cargo). Such a design would be capable of delivering 100,000 to 170,000 lbs of usable cargo into a low-earth orbit.

At the core of the Shuttle-C design is the principle of enhancing the existing Space Transportation System. Consequently, Shuttle-C definition studies have been characterized by relatively low-risk, near-term development and deployment. Shuttle-C is now considered release-ready, pending start approval.

D.2. The National Aero-Space Plane (NASP)

NASP is a presidentially directed program to develop the technology required for a single-stage vehicle using air-breathing primary propulsion to carry payloads into space. The technology development will also lead to the ability to cruise through the atmosphere at sustained hypersonic speeds (i.e. speeds above Mach 5). Follow-on operational vehicles should revolutionize space transportation by providing easier, faster, and more efficient access to space.

The latter stages of the program must be conducted with a flight research vehicle, the *X-30*, since ground-based facilities are inadequate and generally infeasible for speeds above Mach 8. As with previous X-class planes, the program is jointly managed by NASA and the Department of Defense. A team of five primary contractors (General Dynamics, McDonnell Douglas, Pratt & Whitney, Rocketdyne, and Rockwell International) are now sharing their knowledge to produce the best possible vehicle. A decision on whether to proceed to the building and flight testing of the *X-30* will be made in the spring of 1993.

Dramatic progress is being made in technical areas such as propulsion, materials, structures, and aerodynamics. Large-scale production and handling has been achieved with the *X-30* fuel: slush hydrogen, a super-cold combination of liquid and solid hydrogen. Lightweight materials are being developed to withstand temperatures of up to 5000 degrees Fahrenheit, and computational methods used in NASP research can now predict very complex flows on the surface and within the engines of the *X-30* concepts. Such work continues to invigorate a wide range of technologies and to stimulate an even wider range of technology spinoff products.

D.3. Solid Propulsion Integrity Program (SPIP)

SPIP is the product of a joint Department of Defense/NASA study in partnership with private industry that cited critical shortfalls in the U.S. engineering technology base for solid-fuel rocket motors. This collaborative effort is currently reviewing materials, design tools, processing, and inspection techniques so as to

provide NASA engineers with the proper techniques, engineering tools, and computer programs necessary to renew and strengthen U.S. capabilities in this area.

E. ORBITAL DEBRIS

Over the past year, NASA has continued and expanded its orbital debris research program, both generically and in support of requirements for Space Station *Freedom*. In 1990, NASA signed an agreement with the U.S. Air Force to use the Haystack radar facility to detect debris objects. This observation program will continue with over 1200 hours of observations planned for 1991, 800 hours for 1992, and 700 hours per year after 1992. These observations will serve to decrease the current uncertainty in the estimation of the size of the debris population from 300% down to approximately 50% by 1992. There are also plans for the construction of an additional radar facility, the Haystack Auxiliary, which would be dedicated solely to debris observations.

The *Long Duration Exposure Facility* (LDEF) was returned to Earth in January of 1990, after six years in space. This invaluable source of data is being examined to determine the effects of the debris environment upon its structure and experiments.

Work has progressed on efforts to determine the relationship between the radar cross section and optical image of debris fragments and their actual size. Fragments of an exploded tank are being examined in laboratories using several radar frequencies to better understand the nature of the fragments in orbit. Moreover, debris models continue to be refined and updated.

International contacts and cooperation with the space agencies of other countries have also continued and expanded: NASA met twice with ESA in the biannual Orbital Debris Coordination Meetings. The existing cooperative agreement between NASA and ESA, involving German institutions, was expanded to include cooperative modeling work with the Technical University of Braunschweig, and may soon be expanded again. Radar cross section studies are also continuing with the German radar facility, FGAN.

NASA also met with Japanese officials on general debris research, and NASDA representatives attended the last NASA/ESA meeting. It is expected that these meetings will soon be expanded to become trilateral in nature. NASA and ESA have both been involved in spacecraft shielding research using hypervelocity impact facilities, and have recently reached an agreement to use common test reporting formats and to calibrate instruments using a set of benchmark test cases. It is expected that the same arrangement will be reached with Japan.

III. SPACE STATION FREEDOM

Space Station *Freedom* is the largest cooperative civil science and technology project ever undertaken, and will be constructed, operated, and used by all of its international partners to conduct scientific experiments and develop new technologies. Space Station *Freedom* will also be utilized as an observatory to view the Earth, the solar system, and the universe; as a transportation node to assemble, deploy, and repair payloads and vehicles; and as a unique commercial research and manufacturing facility. Its permanently manned base will act as a building block for the manned exploration program and a stepping stone for human exploration of the solar system.

Space Station *Freedom's* priority user requirements, however, will be life sciences and microgravity research. A controlled space environment is vital for developments in these fields, and will provide the international scientific community with a wealth of useful data.

A key change in the program in 1990 was that management of the polar platform was transferred to NASA's Office of Space Science and Applications (OSSA) in 1990. OSSA has responsibility for the *Earth Observing System* (EOS), and the space station platform was to be the first in a series of polar-orbiting spacecraft to be developed for the EOS program. The move was accomplished to put the development and operation of the platform closer to the scientists who would utilize it.

In 1990, *Freedom* completed an Integrated System Preliminary Design Review, a culmination of the preliminary design reviews conducted by all the NASA centers and their prime contractors with responsibility for *Freedom* hardware. In all, over 80 separate design reviews were conducted over the course of the year, focusing on a review of the preliminary design of nearly every major component, subsystem, and system which comprise the station.

The *Freedom* program came to grips with several major resource issues in 1990, including the successful reduction of weight and power increases that surfaced from preliminary design reviews. Preliminary figures for *Freedom's* weight as of June 1990 were 143,000 pounds higher than the allocated limit of 512,000 pounds for the total space station, and housekeeping power exceeded the maximum 45 kilowatts available by nearly 15 kilowatts. An intensive summer-long resources scrub reduced weight estimates by 130,000 pounds, and reduced the housekeeping power by 13 kilowatts. Users will receive 30 kilowatts of power to conduct their experiments.

Another issue resolved in 1990 was the extra vehicular activity maintenance estimates to repair, replace, and maintain *Freedom's* external hardware. A seven-month long assessment concluded that external maintenance would total about 3200 hours of EVA if nothing were done to change current plans. The task force estimated, however that annual EVA hours could be brought down to a manageable 500 hours if NASA followed their recommendations.

A 1991 fiscal budget shortfall of more than $550 million, along with a Congressional mandate to significantly reduce out-year spending, prompted NASA to begin a three-month assessment of the Space Station *Freedom* program. Other ground rules to be followed in conducting the restructuring include: developing a phased approach with quasi-independent phases; protecting life and materials science; maintaining international capability; limiting assembly flights to no more than four annually; and achieving first element launch, man-tended capability, and permanent manned capability as early as possible. At least one option will be developed which holds first element launch at its current date of March 1995.

The resultant restructured program has met all of the ground rules. The restructured station will be smaller, lighter, and easier to assemble and maintain. These changes equate to a $6 billion reduction in development costs over the next five years, while still providing an international space facility devoted to the advancement of life and materials sciences, Earth observation, and space exploration. The new program calls for a First Element Launch in late 1995, a man-tended science capability by late 1996, and a permanently manned capability by late 1999.

IV. SPACE SCIENCE AND APPLICATIONS

A. ASTROPHYSICS

The purpose of NASA's program in Astrophysics is to further human understanding of the universe in which we live. Scientists seek to understand how the universe began, how it evolved, and how it will continue to change in the future. NASA, in cooperation with many other nations, probes the laws of physics and explores the nature of the physical structures of our universe. The strategy of NASA's program embodies several complementary sets of science activities.

A.1. Great Observatories Program

The Great Observatory program consists of four existing or planned orbiting observatories. Each of the observatories will be dedicated to conducting science in one of the four main regions of the electromagnetic spectrum: Infrared, Visible/Ultraviolet, X-rays, and Gamma Rays. The Great Observatories are envisioned as flagship missions, designed to make possible major advances in our scientific understanding of the universe. During 1990, progress continued on all four missions, with one Great Observatory being launched, another being completed and readied for launch in early 1991, a third completing milestones in its development schedule and preparing for a key test of its first set of mirrors in 1991, and the fourth continuing to make progress in its study phase.

A.1.a Hubble Space Telescope (HST)

The first of NASA's Great Observatories, the *Hubble Space Telescope* (HST), was launched aboard the Space Shuttle *Discovery* in April 1990. HST was built in cooperation with the European Space Agency (ESA) to provide an unparalleled view, unhampered by atmospheric distortion, of the universe in visible, ultraviolet and near infrared wavelengths.

Although a flaw in the shape of HST's primary mirror was discovered in June 1990, its effect on astronomical observations has been less severe than originally anticipated. Outstanding scientific research is being conducted with HST. Moreover, instrument upgrades to occur through future Space Shuttle servicing missions will permit nearly all of HST's original scientific objectives to be achieved over its planned 15-year observing lifetime.

NASA supplied the spacecraft, integration, launch services, and four of HST's five scientific instruments: the Wide-Field/Planetary Camera (WF/PC), the Goddard

High Resolution Spectrograph (GHRS), the Faint Object Spectrograph (FOS), and the High Speed Photometer (HSP) . The European Space Agency (ESA) supplied the Faint Object Camera (FOC), HST's solar arrays, and personnel support to the Space Telescope Science Institute, which oversees HST science results.

A.1.b. Gamma Ray Observatory (GRO)

NASA's second Great Observatory, the Gamma Ray Observatory (GRO), is scheduled for launch in April 1991. Built with German participation, GRO will allow scientists to study some of the most energetic and exotic structures in the universe, including pulsars, quasars, novas and supernovas, and active galactic nuclei. As the universe is largely transparent to the transmission of gamma rays, GRO also will be able to probe the center of the Milky Way galaxy for the first time at these wavelengths.

GRO will carry four instruments, with investigators from the U.S., ESA, Germany, and the Netherlands. Germany is furnishing the Compton Telescope (COMPTEL) scientific instrument, as well as key portions of a second instrument, the Energetic Gamma Ray Experiment Telescope (EGRET). The U.S. is furnishing the spacecraft, integration, launch services, as well as the Oriented Scintillation Spectrometer Experiment (OSSE), the Burst and Transient Source Experiment (BATSE), and most of the EGRET instrument.

A.1.c. Advanced X-ray Astrophysics Facility (AXAF)

The Advanced X-ray Astrophysics Facility (AXAF) is currently under development. AXAF will be used by the international scientific community for a 15-year period to examine the X-ray region of the electromagnetic spectrum. AXAF will investigate the existence of black holes, study clusters and superclusters of galaxies, explore the mechanisms by which particles are accelerated to high energies, and examine the contribution of hot gas and "dark matter" to the mass of the universe.

AXAF will have at least one hundred times the capability of any previous X-ray mission, and is scheduled for launch in 1998. A free-flying observatory, AXAF will consist of a nested array of grazing incidence mirrors, up to four focal plane science instruments, and two sets of objective gratings. AXAF is being developed by NASA with participation from Germany, the Netherlands, and the United Kingdom.

A.1.d. Space Infrared Telescope Facility (SIRTF)

The final observatory in NASA's Great Observatories series, the Space Infrared Telescope Facility (SIRTF), will be designed for astrophysical research in the infrared portion of the electromagnetic spectrum. SIRTF will investigate "cooler" celestial

objects, including asteroids, comets, and planetary systems. SIRTF is planned for launch early in the next century.

A.2. Other Operational Astrophysics Spacecraft

A.2.a. Cosmic Background Explorer (COBE)

The Cosmic Background Explorer was developed in-house by NASA's Goddard Space Flight Center (GSFC), and carries three scientific instruments: Far Infrared Absolute Spectrophotometer (FIRAS), Differential Microwave Radiometer (DMR), and Diffuse Infrared Background Experiment (DIRBE). COBE was launched aboard a Delta II from Vandenberg Air Force Base on November 18, 1989, to investigate the earliest stages of organization of matter into galaxies, voids and clusters of galaxies following the Big Bang, to examine departures from perfect uniformity that must have occurred shortly after the Big Bang, and to search for the accumulated light from the very first stars and galaxies.

In 1990, COBE completed its all-sky survey in infrared and microwave radiation and sent back to Earth a clear infrared view of the center of our galaxy, which is usually obscured from view in visible light by interstellar dust. COBE has provided unprecedented measurements of background radiation, providing evidence to support the Big Bang theory of the origin of the universe. During 1990, COBE also returned the most detailed maps ever of the distribution of carbon, nitrogen and cosmic dust within the Milky Way galaxy.

A.2.b. Roentgen Satellite (ROSAT)

ROSAT, a German X-ray spacecraft, was successfully launched aboard a McDonnell Douglas Delta II in June 1990. The spacecraft is a NASA/German Space Agency cooperative program which will provide a detailed survey of the X-ray sources across the sky, followed by studies of some 1,000 of the anticipated 50,000 to 100,000 sources that will be detected. By the end of 1990, ROSAT had successfully completed its 8-week on-orbit checkout and was nearly complete with the 6-month all-sky survey. Pointed observations of sources identified in the all-sky survey are scheduled to commence in early 1991.

Germany supplied the spacecraft, an X-ray Telescope Mirror Assembly, two Position-Sensitive Proportional Counters (PSPC's), and is responsible for orbital operations. The U.S. provided the Delta II launch vehicle and launch services, as well as one of the scientific instruments, the High Resolution Imager (HRI). The United Kingdom provided an extreme ultraviolet Wide Field Camera (WFC).

A.3. Explorer Program

The Explorer program consists of moderate and small-scale missions designed to address highly focused problems in various disciplines of astronomy and space physics. Explorer missions provide a modestly scaled option for scientific research, allowing for quick response to new scientific opportunities. Explorer missions also provide unique opportunities for extended observing periods and hands-on experience for university researchers and students. They constitute a first step for defining and guiding the requirements for major missions and act as complementary extensions of the science conducted by major missions.

A.3.a. Extreme Ultraviolet Explorer (EUVE)

The Extreme Ultraviolet Explorer (EUVE) is designed to conduct an all-sky survey for sources of extreme ultraviolet radiation, to perform follow-up spectroscopic observations on bright sources identified in the all sky survey, to study stellar evolution and the local stellar population, and to study ionization and opacity of the interstellar medium. EUVE consists of four grazing incidence telescopes and a variety of optical filters housed on a reusable Explorer Platform. EUVE is planned for launch in December 1991 on an expendable launch vehicle.

A.3.b. X-ray Timing Explorer (XTE)

The X-ray Timing Explorer (XTE) is designed to study temporal variations in compact x-ray emitting celestial objects. It will include a large area Proportional Counter Array (PCA), an All-Sky Monitor (ASM), and the High-Energy X-ray Experiment (HEXTE). The ASM will provide a constant monitor for x-ray novae and flares while it compiles an all-sky encyclopedic record of variable x-ray sources. XTE is scheduled for launch in 1996.

A.3.c. Advanced Composition Explorer (ACE)

The Advanced Composition Explorer (ACE) mission will observe particles of solar, interplanetary, interstellar and galactic origins. Definitive studies also will be conducted focusing on the abundance of essentially all isotopes from hydrogen to zinc, with exploratory studies extending to zirconium. The ACE study payload consists of six high-resolution spectrometers, each designed to provide optimum charge, mass, or charge-state resolution in a specific energy range. ACE is planned for a late-1990's launch and is being studied by NASA in cooperation with Germany and Switzerland.

A.3.d. Far Ultraviolet Spectroscopic Explorer (FUSE)

The Far Ultraviolet Spectroscopic Explorer (FUSE) will conduct high resolution spectroscopy of faint sources. It will measure the amount of cold, warm, and hot plasma in objects ranging from planets in our solar system, to distant quasars. FUSE is planned for launch around the turn of the century and is being studied by NASA in cooperation with Canada and the United Kingdom.

A.3.e. Small Explorer (SMEX) Program

During 1990, work continued on the Small-Class Explorers selected for development in 1988: the Solar, Anomalous, and Magnetospheric Particle Explorer (SAMPEX), and the Fast Auroral Snapshot Explorer (FAST). Both are designed for research in solar-terrestrial physics. A third mission, the Short-Wave Astronomical Satellite (SWAS), will undertake infrared astronomy measurements. Germany is participating in both the SAMPEX and SWAS missions, which are planned for June 1992 and June 1995 launches, respectively. FAST is scheduled for a September 1994 launch.

B. SOLAR SYSTEM EXPLORATION

NASA's Solar System Exploration Division (SSED) conducts research to determine the present nature of the solar system, its planets, moons, and primitive bodies (asteroids and comets). SSED conducts research to identify and locate other planetary systems in various stages of formation, in order to understand how the solar system and its objects formed, evolved, and (in at least one case) produced environments that could sustain life. SSED is also responsible for comparative planetology, studies undertaken to better understand Earth by determining the general processes that govern all planetary development and by understanding why the "terrestrial" planets of the solar system are so different from each other. Other SSED missions serve to establish the scientific and technical data base for undertaking major human endeavors in space, including the survey of near-Earth resources and the characterization of planetary surfaces.

B.1. Operational Planetary Spacecraft

B.1.a. Magellan

The *Magellan* mission, the first planetary mission in 11 years, was launched aboard the Space Shuttle *Atlantis* on May 4, 1989. This launch marked the beginning of "the second golden age of space science," a 5-year period in which NASA will launch 36 major science missions. The *Magellan* spacecraft is conducting the most

comprehensive observation of the surface and gravitational features of the planet Venus ever undertaken. During its 243-day (one Venus rotation) primary mission, the *Magellan* spacecraft will map at least 70 percent of the planet with high-resolution imaging radar. This radar was designed to reveal surface features to a level which exceeds the performance of all previous U.S. and Soviet missions to our sister planet.

By the end of 1990, the *Magellan* spacecraft had completed almost 100 days of mapping and had already imaged approximately 40 percent of the surface of Venus, returning radar images that show geological features unlike anything seen on Earth. One area discovered is what scientists call "crater farms;" a collection of numerous impact craters formed when asteroids collided with the planet, while another area was covered by a checkered pattern of closely spaced fault lines running at right angles. Most intriguing were indications that Venus may still be geologically active, though much less so than Earth. Scientists hope to map the entire surface of Venus and observe evidence of a volcanic eruption during *Magellan's* mission, which will continue into 1991.

Scientists from Australia, France, and the United Kingdom are participating as co-investigators with U.S. scientists on the *Magellan* project. In addition, three Soviet scientists are participating in the mission, under the terms of the 1987 US-USSR space cooperation agreement.

B.1.b. Galileo

Galileo, the first direct study of the solar system's largest planet, began its 6-year trip to Jupiter on October 18, 1989. During its 22-month encounter with Jupiter, the *Galileo* instruments will conduct detailed studies of the entire Jovian system, including the planet, its ring, and its four major moons: Io, Ganymede, Callisto, and Europa. The *Galileo* spacecraft also will investigate the structure and physical dynamics of the planet's magnetosphere.

During 1990, *Galileo* successfully completed gravity assist flybys of Venus and Earth to give it the energy necessary to reach the Jovian system in late 1995. *Galileo* flew by Venus in February 1990, conducting the first infrared imagery and spectroscopy below the planet's cloud deck. In December 1990, the *Galileo* spacecraft flew by Earth and the Moon, providing spectacular views of our home planet. This fly by constitutes the first encounter of a planetary satellite with Earth. Later in its journey, *Galileo* will also encounter an asteroid in the main asteroid belt between Mars and Jupiter. This will be the world's first close look at an asteroid.

Germany provided part of the spacecraft's propulsion system, two science experiments, and components of five more experiments. U.S. and German scientists

are joined by investigators from Canada, France, Sweden, and the United Kingdom, on the *Galileo* science team.

B.1.c. Ulysses

The *Ulysses* mission is designed to investigate the properties of the heliosphere as a function of solar latitude. *Ulysses* was launched in October of 1990 from the Space Shuttle *Discovery* on a trajectory to intercept Jupiter in February 1992, where it will use the massive Jovian gravity to leave the plane of the ecliptic and be deflected toward the Sun's southern pole. *Ulysses* will overfly the high southern solar latitudes in mid-1994 and the northern latitudes in mid-1995. The mission will be completed in late 1995. ESA provided the spacecraft, its member states provided five of nine science instruments, and ESA integrated the instruments. The U.S. provided the launch vehicle, Radioisotope Thermonuclear Generator (RTG) power source, four science instruments, and mission operations facilities.

B.1.d. Voyagers 1 and 2

Voyagers 1 and 2's working life among the planets in our solar system is now complete; however, these spacecraft are expected to continue returning information about the various fields and particles they encounter while approaching and eventually crossing the boundary of our solar system. The spacecraft generators are expected to maintain the computers, science instruments and radio transmitter for up to 25 or 30 more years. The long-lived project is being called the Voyager Interstellar Mission.

The continuing utility of these spacecraft is confirmed by the fact that discoveries continue to be made. During 1990, a NASA researcher analyzing data from *Voyager 2's* 1980-81 encounter with Saturn discovered evidence of an eighteenth Saturnian moon. Likewise, *Voyager 1* turned its camera towards the Sun and took a family portrait of six of the nine planets in our solar system, the first time such a perspective had been seen.

B.1.e. Pioneers 10 and 11

Pioneer 10, the first spacecraft to leave the solar system, and *Pioneer 11* are currently speeding toward the boundary between the Sun's environment and interstellar space, called the Heliopause. They continue to conduct solar wind and magnetic field studies as they travel through space. Using extensive light measurements made by *Pioneers 10 and 11*, a NASA scientist has produced "celestial constants" that will be highly useful to astronomers and physicists. The new constants are the first "pure" measurements of the various kinds of background light in our solar system, the Milky Way galaxy, and the universe. Scientists continue to search for a possible tenth planet at the fringes of the solar system (as suggested by

past irregularities in the orbits of Uranus and Neptune too large to be completely due to the presence of Pluto) and evidence of extremely long gravity waves, predicted by Einstein's General Theory of Relativity to be the result of cataclysmic events like the collision of galaxies or the formation of black holes.

During 1990, *Pioneer 10* set a distance record by passing the 50 astronomical-unit milestone, 4.6 billion miles from Earth. *Pioneer 11* crossed the orbit of Neptune on February 1990, becoming the fourth spacecraft to leave the solar system (*Voyager 1 and 2* have also left the solar system).

B.1.f. Pioneer Venus Orbiter (PVO)

NASA's *Pioneer Venus Orbiter* (PVO) entered its twelfth year in orbit around Venus in December 1990. The primary objective of the orbiter has been to study solar-wind atmospheric reactions over Venus. PVO provided the first radar survey of the cloud-shrouded planet, and data on the planet's surface and dense cloud cover continued to be collected and analyzed in 1990. The latest research indicates that Venus may have lightning similar to that on Earth.

B.2. Future Solar System Exploration

B.2.a. Mars Observer (MO)

The *Mars Observer* (MO) mission, currently being developed for a 1992 launch aboard a Titan-3 expendable launch vehicle, will place a single spacecraft in a near-polar orbit around Mars to conduct the first long-term U.S. study of Mars as a planet. Instruments on the spacecraft will map and study the entire surface and atmosphere of Mars for a full Martian year (687 Earth days). These observations will determine the planet's global chemical and mineral surface composition and will provide a thorough exploration of Mars' gravitational field, topography, and magnetic field. Of particular interest to scientists is the Martian climate. MO will also study the circulation of Mars' atmosphere and determine the distribution, abundance, and sources of dust and volatile materials over a complete seasonal cycle. MO will begin its 2-year mapping mission in late 1993 after being inserted into a 378-kilometer near-polar Martian orbit.

Scientists from Austria, France, Germany, the Soviet Union, and the United Kingdom are participating in the MO program. Both France and the United Kingdom are providing hardware components for scientific instruments. In addition, MO is being designed to conduct a Mars Balloon Relay (MBR) experiment in cooperation with the Soviet Union and France. The MBR antenna system will relay data and increase the yield of high-resolution imagery obtained from balloons to be deployed on Mars by the Soviet Union's Mars-94 mission, whose two spacecraft will arrive at Mars in late 1995.

B.2.b. CRAF/Cassini Program

Two missions, the Comet Rendezvous Asteroid Flyby (CRAF) and Cassini (a Saturn Orbiter/Titan probe), form the CRAF/Cassini Program, the first in a series of planetary missions whose common objective is to explore primitive bodies and the outer solar system, with the ultimate goal of understanding the origin of our solar system and life itself.

CRAF has two main objectives: a close flyby of at least one large asteroid and a multi-year rendezvous with the short-period comet, Kopff. NASA is cooperating in the development of CRAF with Germany, along similar lines as our existing cooperation in the Galileo mission. NASA will supply the spacecraft, launch vehicle and launch services, and most of the onboard science instruments. Germany will provide components of the propulsion module subsystem, and instrumentation and components for the CRAF payload. Co-investigators on the project come primarily from Germany, but others are from Austria, France, Italy, Japan, the Netherlands and the United Kingdom. CRAF is scheduled for a 1995 launch aboard a Titan IV rocket.

Cassini will be the second mission to utilize the Mariner Mark II spacecraft and is a joint endeavor with ESA. Named in honor of the Italian/French astronomer who discovered four of Saturn's moons, Cassini will conduct a comprehensive scientific investigation of the Saturnian system, including the planet's rings, moons, and the fields and particles in its magnetosphere. An ESA-provided probe, named Huygens, will make in situ measurements of the atmosphere of Titan, Saturn's largest moon, while the Orbiter will make close flybys of a number of the planet's other satellites. Cassini will build on the *Galileo* and CRAF missions flying by at least one asteroid and Jupiter en route to Saturn. A comparison of data from Galileo and Cassini will also be conducted to determine similarities and differences between the Jovian and Saturnian systems. Cassini is scheduled for launch in April 1996 aboard a Titan IV expendable launch vehicle, arriving at Saturn in late 2002.

C. EARTH SCIENCES AND APPLICATIONS

The goal of NASA's Earth Sciences and Applications Division is to conduct a coordinated program of observations and research of the Earth's environment. These missions will increase our understanding and help identify whether these changes are naturally-occurring or induced by human activity. Almost all of the NASA Earth Science and Applications program contributes to Mission to Planet Earth, the Presidential initiative designed to document and comprehend how the Earth works as a system. Mission to Planet Earth, is the NASA contribution to the U.S. Global Change Research Program, which is a multi-agency effort to answer the critical questions of global change. Results from this program, in turn, contribute to global

research programs coordinated by the international community and foreign governments and organizations.

C.1. Earth Observing System (EOS)

EOS consists of a space-based observing system, a comprehensive Data and Information System (EOSDIS), and a scientific research program. The space-based observatory system will provide long term (15-year) data sets for Earth system science to gain an understanding of the global hydrological cycle, the global biogeochemical cycle, and global climate processes. Specific areas of study will include hydrology, oceanography, atmospheric chemistry and dynamics, geology, forestry, snow and ice observations, ozone depletion and greenhouse gases. Each observatory will consist of an integrated platform and instrument payload complement. EOS represents the initiation of a comprehensive, global observing system with high spectral and spatial resolution, as well as long-term temporal coverage of the Earth. The space component will consist of a series of polar-orbiting spacecraft, with launch of the first spacecraft planned for 1998. EOS will be complemented by companion European and Japanese spacecraft, as well as continuing observations by operational environmental satellites.

The EOS Program will also include development of a comprehensive Earth Observing System (EOS) Data and Information System (EOSDIS). The EOSDIS will be designed to maximize the Earth science research community's access to, and processing of, the necessary data through an open data policy. In addition to the traditional disciplinary science approach, EOS will support researchers focused on the interdisciplinary evaluation of EOS data. This includes funding of post-graduate fellowships, interdisciplinary science team grants, and Principal Investigator research grants.

EOS will build on and integrate the measurements conducted by precursor research missions. It will provide the first coordinated simultaneous measurements of the interactions of the atmosphere, oceans, solid Earth, and hydrologic and biogeochemical cycles. As the cornerstone of Mission to Planet Earth, EOS will be one of the largest science missions ever undertaken, providing comprehensive data on Earth's atmosphere, oceans and land. It will help the international scientific community to understand the complex interactions of our environment, to assess humanity's role in shaping them, and to build credible models capable of predicting future change. Instruments from the U.S., Canada, Europe and Japan have been selected for flight on EOS, and over 500 scientists from 13 countries have been identified to participate in the EOS program.

C.2. Earth Probes

The Earth Probes Program is composed of a series of small- and moderate-sized missions that will address highly focused problems in Earth science. This Explorer-class program will initiate or continue pre-EOS long-term data sets, and may capture measurements that are not possible with EOS or other instrument suites. Each free flyer or instrument has a specific purpose, providing critical measurements of particular phenomenon, but requiring a unique orbit or configuration not always available from EOS missions.

C.2.a. Total Ozone Mapping Spectrometer (TOMS)

The Total Ozone Mapping Spectrometer (TOMS) measures total ozone concentrations. Information gathered on atmospheric composition will continue the long-term data set being gathered by the TOMS instrument on Nimbus-7 (1978-present). To support Antarctic scientists in their ozone campaign, scientists at NASA's Goddard Space Flight Center have been processing the data from the TOMS instrument on Nimbus-7 in near real-time and observations are transmitted to researchers around the world. Recent TOMS gathered data showed that the ozone levels over Antarctica between August and October were as low in 1989 and 1990 as the record low levels measured in 1987.

TOMS will allow time series evaluations to establish trends, with the goal of studying the question of global and regional changes in ozone levels. Ancillary data products will reveal lower stratosphere/tropopause dynamics and allow detection of sulfur dioxide clouds resulting from major volcanic eruptions. TOMS serves as a precursor to NOAA instrumentation in the EOS time frame. The next TOMS instrument will be flown aboard a Soviet Meteor-3 satellite in mid-1991, followed by the launch of a U.S. satellite in 1993, and the flight of another TOMS instrument on the Japanese ADEOS satellite in 1995.

C.2.b. NASA Scatterometer (NSCAT)

The NASA Scatterometer (NSCAT) is a satellite radar designed to measure wind speed and direction over more than 90 percent of the Earth's oceans every 2 days. A scatterometer measures the return power of radar energy scattered by small ripples on the sea surface. This measurement is affected by wind speed, the angle of the wind to the radar beam, and the angle of the radar beam to the vertical. NSCAT measurements will allow calculation of large-scale fluxes of momentum, heat, and moisture between the atmosphere and ocean, thereby, contributing essential information to studies on air-sea coupling and interannual variability of the Earth's climate. Observational analyses and modeling studies applying NSCAT data will yield a better understanding of the coupled circulations of the oceans, atmosphere

and climate. This instrument has been selected for flight on the Japanese Advanced Earth Observing Satellite (ADEOS) in 1995.

C.2.c. Tropical Rainfall Measuring Mission (TRMM)

The Tropical Rainfall Measuring Mission (TRMM) will measure diurnal variation of precipitation and evaporation in the tropics, providing increased understanding of how substantial rainfall affects global climate patterns. The goal of this mission is to obtain a minimum of 3 years of climatologically significant observations of rainfall in the tropics, and, in tandem with cloud models, to provide accurate estimates of the vertical distributions of latent heating in the atmosphere. TRMM is a joint venture with Japan, and will be launched on a Japanese H-2 rocket in the mid-to-late 1990's.

C.3. Near-Term Spacecraft Programs

C.3.a. Upper Atmosphere Research Satellite (UARS)

The Earth's upper atmosphere plays a fundamental role in global climate and provides our shield against harmful ultraviolet radiation from the Sun. UARS is the spearhead of a long-term, international program of space research into global atmospheric change. The UARS program will conduct the first systematic, detailed satellite study of the Earth's stratosphere, mesosphere, and lower thermosphere and establish the comprehensive data base needed for an understanding of stratospheric ozone depletion. Scheduled for deployment by the Space Shuttle in 1991, the UARS mission will also lay the foundation for a broader study of upper-atmosphere influence on climate and climactic variations.

An important aspect of the UARS program is its coordination with additional national and international programs of study and data acquisition. The United Kingdom, Canada and France are contributing UARS instruments, and scientists from many nations will ultimately participate in the analysis and utilization of UARS data. Upon completion of the UARS mission, the international scientific community will have gained a dramatically expanded and detailed picture of the energetics, dynamics, and chemistry of the upper atmosphere. This information will then be available to governments around the world, enabling them to address more effectively the role of human activities in altering upper-atmosphere properties.

C.3.b. Ocean Topography Experiment (TOPEX/POSEIDON)

TOPEX/POSEIDON, a joint program between NASA and the French National Center for Space Studies (CNES), is designed to measure currents by using a satellite equipped with precision altimeters to map ocean topography with an accuracy on the order of 15 centimeters (6 inches). Ocean surface topography is associated with

ocean circulation caused by currents. Other scientific objectives of the TOPEX/POSEIDON mission are the study of ocean tides, ocean heat transport, statistics of ocean variability, the marine geoid, and geophysical studies of lithospheric and mantle processes.

In addition to the Ariane 4 launch vehicle, CNES will provide an experimental single frequency solid state altimeter and a radiometric Doppler tracking system named DORIS. NASA will provide the spacecraft and instrument integration, an advanced dual-frequency altimeter, microwave radiometer, retroreflectors for ground based laser tracking and an experimental Global Positioning System tracking receiver. NASA and CNES have selected an international team of scientists representing the U.S., Australia, France, Germany, Japan, the Netherlands, Norway, South Africa and the United Kingdom.

The TOPEX/POSEIDON dataset will serve as the centerpiece of the World Ocean Circulation Experiment (WOCE), an international project that is a component of the World Climate Research Program. WOCE will result in the first comprehensive study of the physical properties of the oceans, and will contribute to successful prediction of global climactic change on the scale of decades. TOPEX/POSEIDON will also contribute to the Tropical Ocean Global Atmosphere (TOGA) program.

C.3.c. Laser Geodynamics Satellite-2 (LAGEOS-2)

LAGEOS-2 is being developed under a joint agreement between NASA and the Italian Space Agency (ASI). Like its predecessor LAGEOS-1 (launched by NASA in 1976), LAGEOS-2 will be a small spherical satellite covered with 426 retroreflectors. Its spherical shape and retroreflectors are designed to reflect laser beams aimed at the satellite from ground stations located across the globe. Any shift in the position of the Earth's crust greater than two centimeters can be detected by changes in the round trip travel time of the laser beams. Such information is extremely important for monitoring fault movements in regions of the world that are prone to earthquakes.

LAGEOS-2 will have the same circular orbit as LAGEOS-1, but its angle of orientation will be different (52 degrees inclination instead of 110 degrees). By tracking both of the satellites, the accuracy of the data obtained is expected to improve by a factor of two. It may permit researchers to measure the Earth's rotation rate, the oceans' tidal dissipation, and the rate of separation between the Earth and the moon. LAGEOS-1 and -2 are precursors to the Geoscience Laser Ranging System (GLRS) on the Earth Observing System (EOS), which will reverse the traditional approach of laser ranging by putting the laser source in orbit and the retroreflectors on the ground.

Italy is responsible for fabrication of LAGEOS-2 and for its integration with a spinning upper stage known as the Italian Research Interim Stage (IRIS) that can be used to deploy light-weight satellites from the Space Shuttle. The U.S. will furnish existing ground support equipment, conduct optical tests of the satellite, and launch the satellite from the Shuttle. In 1989, an international team of 27 investigators was selected representing the following six countries: the U.S., France, Germany, Hungary, Italy, and the Netherlands. LAGEOS-2 is scheduled for a 1992 launch.

C.4. On-going Programs

C.4.a. Earth Radiation Budget Experiment (ERBE)

ERBE consists of instruments carried by three satellites: the Earth Radiation Budget Experiment (ERBE) and two NOAA-series polar orbiting weather satellites, NOAA-9 and NOAA-10. Data obtained from these satellites has indicated that the type of cloud and its altitude determine what effect these clouds have on the Earth's climate. The ERBE database will be complemented by the International Satellite Cloud Climatology Project (ISCCP), a joint program of the World Meteorological Organization and the International Council of Scientific Unions, to create a dataset from which to infer the global distribution of cloud radiation properties. NASA is responsible for processing and combining the data from meteorological satellites operated by the U.S., ESA, and Japan.

C.4.b. Global Tropospheric Experiment (GTE)

The Global Tropospheric Experiment (GTE) is a series of experiments with two main goals related to tropospheric chemistry. One goal is to determine the susceptibility of the Earth's atmosphere to chemical change, as evidenced through a series of field measurements. Collectively these field expeditions are referred to as the Atmospheric Boundary Layer Experiments (ABLE). The second goal is to evaluate the performance of instruments being developed to measure various trace elements in the atmosphere, through a program called Chemical Instrumentation Test and Evaluation (CITE).

Researchers from NASA, NOAA, and NSF selected several ecosystems for field studies that are particularly important as atmospheric change agents. Areas selected for study include tropical Atlantic, Amazon rain forests of Brazil, Arctic tundra and subarctic peatlands (conducted from Alaska), and Canadian wetlands. All of the GTE-ABLE investigations use a combination of ground-based, aircraft and satellite monitoring.

In the 1990's, a series of aircraft missions called GTE/PEM (Pacific Exploratory Missions) will focus on making measurements of concentration and distribution of atmospheric trace gases important to the "greenhouse effect". There will be four PEM

experiments beginning in 1991. In 1992, the GTE/TRACE-A (Transport and Chemistry near the Equator-Atlantic) campaign will be initiated to study the impact of biomass burning in Brazil and Africa on tropospheric ozone over the South Atlantic. Foreign investigators can propose experiments for participation in both PEM and TRACE-A.

C.4.c. Boreal Forest Field Study

NASA is currently planning a major Boreal Forest Field Study. The preliminary experiment plan, published in April 1989, calls for surface, airborne, and satellite observations to investigate interactions between the boreal forest biome and the atmosphere in order to clarify their roles in global change. The Boreal Forest Study will combine elements of terrestrial ecology, land surface climatology, and tropospheric chemistry to understand the major exchanges of radiation, heat, and trace gases. Collaboration with Canada has been discussed, and a joint U.S.-Canada Science Steering Committee has been formed to further the scientific planning for the 1993-1994 field campaigns.

C.4.d. Airborne Arctic Ozone Experiments

The Arctic Ozone Campaign was undertaken to examine the chemical and dynamical processes that control ozone in the Arctic winter stratosphere. The overall goal of the mission is to establish whether the processes that contribute to the Antarctic ozone depletion are operative in the northern hemisphere. The key findings of the 1989 Airborne Arctic Stratospheric Expedition were that the chemical composition of the Arctic polar stratosphere was found to be highly perturbed. The latest 1990 results indicate that chemical processes that lead to ozone depletion in the Antarctic are present in the far Northern hemisphere, and some regions of the Arctic stratosphere may have suffered ozone losses up to 17 percent during the winter of 1988-89.

In addition to scientists, managers, and aircraft crew from NASA and the National Oceanic and Atmospheric Administration (NOAA), scientists and technicians from the National Science Foundation's (NSF) National Center for Atmospheric Research, the United Kingdom (U.K.) Meteorological Office, the U.K. Department of Environment, the University of Oslo, and the Norwegian Meteorological Office participated in the project. Additional data was supplied by Danish, German and Soviet balloon sounding teams located throughout the Arctic region.

C.4.e. Alaska Synthetic Aperture Radar Facility (ASF)

In 1989, NASA continued installation of a Synthetic Aperture Radar (SAR) receiving station that will be located at the University of Alaska at Fairbanks. The

ASF ten-meter antenna will be able to receive signals from Canadian, European and Japanese satellites carrying SAR devices to produce images of ice formations, land, and seas in and around Alaska, western Canada, and eastern Siberia. Among the results that scientists hope to obtain is a description of the Arctic ice pack in terms of its ice type, flow size, open water distribution, and the motion of the ice. Understanding the polar oceans and ice pack is important because the temperature differential between the cold polar atmosphere and the warmer oceans makes the Arctic a site of great heat loss, with significant impact on the global climate system.

The facility is scheduled to be fully operational in time for the 1991 launch of European remote sensing satellite (ERS-1), which will carry a C-band frequency SAR primarily to produce high resolution maps of the Arctic oceans and ice pack. ASF will receive and process data from the ESA ERS-1 Satellite as well as from the Japanese Earth Resources Satellite (J-ERS-1), which includes an L-band SAR that will focus mainly on land-based applications and is scheduled for a 1992 launch. RADARSAT, carrying a Canadian-led multinational C-band SAR for ocean and sea ice monitoring, will be the third satellite to provide direct data to the ASF.

The location of the ASF will complement other SAR receiving facilities that will be located under ESA direction in Canada, Norway, Sweden, and the United Kingdom. Together, these stations will provide SAR coverage of nearly all northern mid- and high-latitude regions. Further complements will be provided through a major research project called the Program for International Polar Ocean Research (PIPOR). PIPOR will apply ERS-1 SAR data to ocean and ice research problems. This project involves more than 100 investigators from Australia, Europe, Japan and North America.

C.4.f. Advanced Sensor Development

Advanced airborne sensors which are prototypes for Earth Observing System (EOS) instruments continue to play an important role in the Land Processes studies. Highlights from 1990 include flights by the AVIRIS (Airborne Visible Infrared Imaging Spectrometer) and the airborne SAR (Synthetic Aperture Radar) in support of scientific investigations. AVIRIS is the prototype for the EOS HIRIS (High Resolution Imaging Spectrometer), and the SAR is the prototype for the planned EOS SAR.

D. SPACE PHYSICS

NASA's Space Physics Division supports investigations of the origin, evolution, and interactions of space plasmas. Programs in this division focus on the upper atmosphere, ionosphere, and magnetosphere of Earth; the Sun as a star and as

a source of solar system energy, plasma, and energetic particles; and, the acceleration, transport, and interactions of energetic particles and plasmas throughout our solar system and the Milky Way galaxy.

Observations, theory, modeling, simulations, laboratory studies, interactive data analysis, instrument development, and active experiments are all important aspects of the program. Observations are made from a variety of bases including the ground, on high altitude balloons and sounding rockets, and from orbiting satellites.

D.1. International Solar-Terrestrial Physics (ISTP) Program

NASA will support coordinated international solar-terrestrial physics-related mission activity in the 1990's through the International Solar-Terrestrial Physics (ISTP) Program. The objectives of the ISTP program are to comprehensively measure and study phenomena associated with Sun-Earth interaction, in particular, the generation of energy and plasma from the Sun and their effects on the Earth's magnetosphere, ionosphere, and atmosphere. The ISTP program comprises two major subprograms: the Global Geospace Science (GGS) program, and the ESA/NASA Solar-Terrestrial Science Programme (STSP).

The Global Geospace Science (GGS) program will make coordinated measurements of the energy flow from the Sun through four key plasma source areas of geospace and to provide the first comprehensive, multi-point studies of global magnetospheric response to the solar wind. The global energy objectives of GGS require the simultaneous acquisition of data from each of these key magnetospheric regions. Several missions are part of the GGS Program: Wind mission, manifested for launch in December 1992; Polar mission, manifested for launch in June 1993; Geotail mission, a joint NASA/ISAS (Institute of Space and Astronautical Sciences of Japan) mission, scheduled for a July 1992 launch; and, the extended mission of the NASA/U.S. Air Force Combined Release and Radiation Effects Satellite (CRRES), launched in July 1990.

NASA's Wind mission will provide the solar wind input function, while the NASA Polar mission will examine the deposition of the ionosphere's energy using global auroral imaging from polar orbit. The CRRES extended mission will study the acceleration of energy in the Earth's equatorial region, while Geotail, as its name implies, will measure energy flow, storage, and transformation in the geotail of the Earth's magnetosphere. NASA will contribute instruments and launch the Japanese Geotail spacecraft. The entire GGS project is expected to have a total of approximately 200 investigators from many different nations. NASA will also provide tracking services for Wind, Polar and Geotail through NASA's Deep Space Network (DSN).

D.2. Solar Terrestrial Science Program

The Solar Terrestrial Science Program (STSP) is a joint endeavor by ESA and NASA to study solar, heliospheric, and space plasma physics. STSP consists of two separate spacecraft investigations: the Solar and Heliospheric Observatory (SOHO) and a group of four coordinated satellites known as Cluster. ESA will develop the spacecraft for SOHO and Cluster. NASA will launch the SOHO spacecraft aboard an expendable launch vehicle in March 1995. ESA will launch the Cluster spacecraft aboard an Ariane V in December 1995. Experiments on the spacecraft will be provided by U.S. and European scientists.

The SOHO mission has two main purposes. One is to make long-term uninterrupted measurements of the Sun's oscillation properties, as well as measurements of its velocity and irradiance. Space physicists believe these investigations will provide important clues about the Sun's interior and internal dynamics, which in turn have important implications for the accuracy of various stellar theories. SOHO's second goal is to study the solar corona and solar abundance as an integrated system.

The Cluster spacecraft will make simultaneous scientific observations of those small-scale processes critical to understanding how the solar wind interacts with the Earth's magnetosphere. Using four spacecraft, Cluster will provide a three-dimensional study of the microphysical properties of the magnetosphere. Cluster may be enhanced by spacecraft from the planned Regatta series provided by the Soviet Union's Institute of Space Research (IKI) which will perform complementary measurements in the polar magnetosphere.

D.3. Suborbital Program

The goal of NASA's Suborbital Program is to conduct research into the physical processes operating in the upper atmosphere and space through the use of balloons, sounding rockets, and of instruments onboard the Shuttle.

The main objective of NASA's sounding rocket program is to provide the means to get above the Earth's atmosphere in order to conduct astrophysics, solar physics, and space physics experiments. NASA's Wallops Flight Facility manages this program and is responsible for an average of 40 flights a year. Several launch sites are utilized of which White Sands, New Mexico, is the most heavily used. NASA utilizes a number of foreign launch sites under cooperative agreements and also uses sounding rocket launch sites in Australia, Canada, Norway, Peru, Puerto Rico, and Sweden. In 1990, NASA launched seven suborbital sounding rockets from the Roi-Namur launch facility in the Kwajelein Atoll in the Republic of the Marshall Islands. Four of these launches will complement the science objectives of the

Combined Release and Radiation Effects Satellite (CRRES), while the remaining three will comprise the Equatorial Ionospheric Studies (EQUIS) program.

Short-lived satellite shuttle flights mainly revolve around the Hitchhiker program designed to permit people to build small self-contained experiments to be put up on the Shuttle. Scientists propose such investigations and then, the "hitchhiking" packages are chosen and flown. Most investigations essentially involve the magnetosphere and ionosphere.

E. LIFE SCIENCES

The goals of NASA's Life Sciences Program are to ensure the health, well-being, and performance of humans in space, develop an understanding of the role of gravity on living systems in space, expand our understanding of the origin, evolution, and distribution of life in the universe, and promote the application of life sciences research to improve the quality of life on Earth.

E.1. Spacelab Life Sciences (SLS) Missions

In 1990, planning continued for the first Spacelab Life Sciences mission (SLS-1), scheduled for launch on board *Columbia* in May 1991. The SLS missions are dedicated to understanding how living systems adapt to weightlessness. Both SLS-1 and SLS-2 will focus on early physiological responses to weightlessness such as acute fluid shift, cardiovascular adaptation, and space motion sickness. Eighteen primary and eleven secondary payloads for SLS-1 have already been selected, including an experiment on the effects of weightlessness on human lymphocyte proliferation sponsored by the Swiss Federal Institute of Technology, and another on the role of myosin isoenzymes and the alteration of muscles using the inflight monitoring and postflight tissue analysis of rats, proposed by the University of Sydney, Australia. Scientists anticipate that the SLS missions will increase confidence in their estimates of the physiological consequences of weightlessness, and will enhance their ability to manage and reduce its adverse effects.

E.2. Extended Duration Orbiter (EDO) Program

The EDO program is a response to the requirement to extend Space Shuttle mission duration to 16 days. The extended flight times create physiological demands on the crew members that cannot be adequately assessed using current information. The Space Shuttle differs from previous spacecraft because the crew, while readapting to the Earth's gravitational field, must perform reentry, landing, and egress operations that require proficiency and physical capabilities that were not needed before the Shuttle era.

From previous Shuttle flights, it has become apparent that new procedures and countermeasures need to be developed to ensure the safety and success of EDO missions. During the EDO Program, a database will be developed to define and understand the operational significance of flight-induced alterations in physiology. Procedures and countermeasures for optimizing crew performance for nominal and contingency entry, landing, and egress during extended missions will be developed and verified. Emphasis will be placed on maintaining orthostatic tolerance, exercise capacity, and sensorimotor function. Also, Shuttle EDO environmental and monitoring requirements for air quality, water potability, surface contamination, radiation, waste management, and general habitability will require upgrading. A significant part of the International Microgravity Laboratory-2 payload will be dedicated to EDO program studies.

E.3. Centrifuge Facility Program

Definition and design of the Centrifuge Facility continued in 1990. The Centrifuge Facility includes a variable speed centrifuge; habitats for rodents, plants, and small animals; a multi-purpose glovebox and workbench; and a specimen chamber resupply unit. The Centrifuge Facility will provide life scientists with the ability to vary gravitational force on a broad range of living species, under completely controlled conditions, for extended periods of time on board Space Station *Freedom*. For the first time it will be possible to keep living specimens at gravity levels up to the level of gravity experienced on Earth, while at the same time periodically exposing them to weightlessness and the other effects of space flight. The centrifuge will also permit scientists to use gravity as an experimental variable. They will be able to alter the gravity level the organisms are exposed to, in order to discover how it affects physical functions like growth and development. The centrifuge may also make it possible to determine if artificial gravity is an effective countermeasure against the adverse physiological effects of prolonged time in space.

E.4. Controlled Ecological Life Support System (CELSS)

Development of a regenerative life support system with enhanced efficiency for food production and waste re-cycling involves two basic, integrated functions: physical/chemical life support elements, and biological life support elements in a system that is known as CELSS. NASA's Life Sciences Division is responsible for mission operational system requirements for both physical and chemical life support systems and for technology development for CELSS.

The CELSS Program was initiated on the premise that NASA's goals would eventually include extended-duration missions with sizeable crews requiring capabilities beyond the ability of conventional life support technology. Currently, as mission duration and crew size increase, the mass and volume required for consumable life support supplies also increases in direct proportion. Under these

circumstances, the logistics arrangements and associated costs for life support resupply will adversely affect the ability of NASA to conduct long-duration missions. A solution to the problem is to develop technology for the recycling of life support supplies from wastes. The CELSS concept is based upon the integration of biological and physio-chemical processes to construct a system that will produce food, potable water, and a breathable atmosphere from metabolic and other wastes, in a stable, reliable manner.

Essential in CELSS development are investigations and technology development in the areas of plant growth, food processing, energy balance, waste processing, sensing, controls, and automated systems. It must also be determined whether full size plants can grow productively in microgravity. In 1990, definition studies continued on the CELSS program. NASA planning involves developing a ground-based CELSS within a decade, along with flight-certified hardware; pursuing opportunities to fly CELSS experiments; and, ultimately, designing a space-based CELSS system.

E.5. Search for Extraterrestrial Intelligence (SETI) Microwave Observing Project

Over the past 20 years, NASA has conducted extensive studies on the feasibility of carrying out a Search for Extraterrestrial Intelligence (SETI). From 1983 to 1989, NASA's Ames Research Center and Jet Propulsion Laboratory jointly conducted an engineering development program to design a SETI system capable of conducting an extended search of the microwave portion of the electromagnetic spectrum. In October 1989, NASA formally initiated the SETI Microwave Observing Project as an element in the Exobiology Program conducted by the Life Sciences Division.

The Exobiology Program seeks to understand the origin, evolution, and distribution of life in the universe. The SETI Microwave Observing Project is designed to address the hypothesis that life, including intelligent life, may be widespread in this galaxy. It is generally agreed that a technically feasible and promising method of detecting extraterrestrial civilizations which are not currently within reach of spaceflight missions is by the detection of microwave signals they may be transmitting. Beginning in 1992, the SETI Microwave Observing Project will conduct a systematic search of the terrestrial microwave window (1-10 GHz), where background radio emissions are at a minimum. The search systems will be very sensitive to an extended class of signals that are compressed in frequency and perhaps also in time and that, as far as we know, are not produced by other astrophysical processes.

E.6. Lifesat

In January 1989, NASA released a Request For Proposals (RFP) for continued studies leading to the design and construction of an unmanned reusable reentry satellite. Such a satellite would greatly expand NASA's capability to undertake extended duration studies in the weightless environment of space, particularly in the life sciences and microgravity sciences areas. When the satellite is carrying life sciences specimens, it will be referred to as Lifesat. Lifesat will be launched by expendable launch vehicles and be capable of staying in space for up to 60 days at a time. It will also be able to fly experiments in a number of different orbits, including those at a higher latitude than Spacelabs, which will create an opportunity to study the effects of more intense radiation dosages. Its design will enable it to reenter in a controlled soft landing at a predetermined site. Modules planned for Lifesat include a general biology module, a rodent module, and a botany module.

Over the long term, Lifesat will serve as a complement to the continuing Spacelab series of missions and the facilities on Space Station *Freedom*. The Lifesat concept has resulted in international interest in Japan, Canada, France, Germany, and ESA. Parallel studies continued in 1990.

F. MICROGRAVITY SCIENCE AND APPLICATIONS

NASA's Microgravity Science and Applications (MSA) Program is conducted jointly through the Microgravity Science and Applications Division of OSSA and by the Office of Commercial Programs (OCP). The mission of NASA's Microgravity Science and Applications Division (MSAD) is to utilize the reduced gravity environment in space to conduct research in fundamental science, materials science, and biotechnology.

Studies conducted under these unique conditions can help clarify the roles of factors normally masked by or in competition with gravity-induced phenomena in complex physical processes. The resulting knowledge benefits both Earth- and space-based technology. The near elimination of gravity is also exploited to process selected materials in unique ways. For example, the extremely quiescent environment is conducive to the growth of larger and more perfect inorganic and protein crystals that can be grown on Earth. These and other high-value space processed materials may have important applications, including the development of new pharmaceutical products and advance engineering materials.

F.1. Ground-Based Microgravity Science Research

The primary functions of the MSAD ground-based research program are to develop concepts that will lead to flight experiments; to determine limitations of various terrestrial processing techniques; and to provide analysis and modeling

support to the flight program. NASA supports this research program by using specialized ground-based facilities to complement a limited number of Space Shuttle flight opportunities.

Microgravity science and applications research requirements have influenced the development of ground-based facilities with a variety of experimental capabilities. Drop towers, drop tubes, and aircraft flying parabolic profiles constitute NASA's most important ground-based assets for the simulation of microgravity conditions. These facilities contribute significantly to the experimental advancement of microgravity science, even though near-weightless periods last only a few seconds. The availability and cost-effectiveness of these facilities relative to extended Shuttle flight opportunities make them useful in the advancement of scientific theories, evaluation of instrumentation, and testing of prototype experiment hardware prior to flight. Additional ground-based testing capabilities are provided by expendable suborbital sounding rockets.

F.2. Flight-Based Microgravity Science Research

Presently, the Space Shuttle is the primary U.S. platform for microgravity science research. Most of the flight experiment hardware currently being designed will be flown aboard the Shuttle, in the middeck and in dedicated pressurized laboratories or Spacelabs. Highly automated payloads may also be flown in special self-contained canisters known as "Get-Away-Specials", in the Shuttle cargo bay.

Typical Shuttle missions of 7 to 14 days greatly extend the time available for the conduct of microgravity experiments. These extended periods are needed to more thoroughly investigate a variety of phenomena which do not reach equilibrium in the short periods of microgravity afforded by specialized ground-based facilities. Studies ranging from the dynamic behavior of fluids, to combustion and fire safety, to investigations of fundamental physical principals are planned in the microgravity science program. The scope of the materials science research encompasses the processing of electronic and photonic materials; metals and alloys; glasses and ceramics; and polymers. The microgravity science research program also includes biotechnology research in the areas of macromolecular cell growth, protein crystal growth, and biological material separation techniques. To complement flight opportunities offered by the Space Shuttle, the use of alternate payload carriers such as free-flying spacecraft, orbital platforms launched by unmanned expendable vehicles, and suborbital sounding rockets, are also being examined. In 1990, Space Shuttle middeck payloads included experiments designed to investigate how protein crystals grow and how flames spread in the absence of Earth's gravity.

F.3. United States Microgravity Laboratory (USML) Mission Series

United States Microgravity Laboratory (USML) missions will offer U.S. investigators major opportunities to conduct microgravity research in space, using primarily hardware developed in the U.S. These missions will take place aboard dedicated, pressurized Spacelab laboratories. Four USML missions are scheduled beginning in 1992 and continuing at approximately 2-year intervals thereafter. NASA will provide the launch service, define and integrate the payloads, and maintain responsibility for mission management. The USML missions complement the International Microgravity Laboratory (IML) missions, and are viewed as an essential stepping stone in the development of technology, hardware, and operational procedures for microgravity science applications aboard Space Station *Freedom*.

Presently, the first flight of the U.S. Microgravity Laboratory (USML-1), scheduled for June 1992, represents the highest priority near-term flight opportunity for U.S. microgravity experiments. Four major experiments, including the Drop Physics Module, the Crystal Growth Furnace, the Surface Tension Driven Convection Experiment, and the Solid Surface Combustion Experiment have been scheduled for that mission.

F.4. International Microgravity Laboratory (IML) Missions

The International Microgravity Laboratory (IML) missions will extend major opportunities for microgravity research to the international scientific community. These missions will offer the use of predominantly foreign-developed hardware to both U.S. and foreign investigators. As with the USML series, NASA will provide the flight opportunities, define and integrate the payloads, and manage the missions for IML. IML is specifically conceived as a laboratory research program using multiple application instruments on frequent flights with minimal disassembling or modification between missions. It will serve as a test bed for Space Station *Freedom* cooperation in the microgravity science field.

Through six international space science research organizations, more than 200 scientists from 13 countries are collaborating with NASA on the IML-1 mission, scheduled for a December 1991 launch, in order to provide the worldwide science community with a variety of complementary facilities and experiments. Foreign experiments and experimental hardware selected for IML-1 include: The European Space Agency-supplied Biorack, which can be used to study the effects of microgravity and cosmic radiation on up to 150 types of plants, insects, tissues, cells, and bacteria; the CNES-developed Mercury-Iodide Crystal Growth (MICG) Facility for the study of the effects of gases on the nucleation of mercury iodide in microgravity; the Canadian Space Agency's Space Physiology Experiments (SPE), a set of six experiments to study how the human nervous system adapts to weightlessness; the Organic Crystal Growth Facility sponsored by the National Space Development Agency of Japan (NASDA); and the Cryostat, a temperature-controlled protein crystal growth experiment contributed by the German Aerospace Researcg

Establishment. Payload specialists for the IML and USML missions will be actively involved in many of the investigations as trained scientists performing experiments on-orbit and providing scientific analysis of experiment progress to investigators on the ground.

F.5. United States Microgravity Payload (USMP) Mission Series

The USMP is an automated, unpressurized system resident in the Shuttle payload bay. It is an additional payload configuration, beside the IML and USML, that will fly multi-user and experiment-unique equipment aboard the Space Shuttle periodically over at least the next 6 years. Use of the equipment aboard USMP experiment missions will provide precursors from which Space Station microgravity facilities will evolve.

Five USMP missions are currently scheduled through 1996. The first USMP mission (USMP-1) has been manifested for flight aboard STS-52 in September 1992. USMP-1 experiments include the Advanced Automated Directional Solidification Furnace (AADSF), which will be useful for investigations into the roles of gravity-induced phenomena in the growth of crystals; and the "Lambda Point" Experiment (LPE), developed at Stanford University in conjunction with NASA's Jet Propulsion Laboratory. This experiment will very accurately determine the heat capacity of a liquid helium sample as it repetitively traverses its transition point under microgravity conditions. This important experiment will test the limits of validity of the Group Renormalization Theory, dealing with the universality of the behavior of matter near critical phase transition, which earned a Nobel prize for its author in 1982.

F.6 Microgravity Science and Applications Program Aboard Space Station Freedom

Space Station *Freedom* (SSF) will provide a stable platform on which highly productive and flexible microgravity science experiment modules can be based. A key long term program goal remains the development of several multiuser facilities specifically designed for long duration scientific research missions aboard the SSF. Six multiuser facilities are currently envisioned for SSF: the Space Station Furnace Facility (SSFF); the Modular Containerless Processing Facility (MCPF); the Advanced Protein Crystal Growth Facility (APCGF); the Biotechnology Facility (BTF); the Modular Combustion Facility (MCF); and the Fluid Physics/Dynamics Facility (FPDF). These facilities will each accommodate a variety of investigations in several critical scientific disciplines well suited to space experimentation. Although their design requirements are currently evolving, they will be modular and readily adaptable to the needs of individual investigators for many years. The facilities will be transported to Space Station *Freedom* over an extended time frame beginning in the mid-1990's. Operation of the first facility, the APCGF, is planned for 1996.

G. COMMUNICATIONS AND INFORMATION SYSTEMS

NASA communications research focuses on developing and demonstrating microwave, optical, and digital technologies to increase the capacity, flexibility, and interconnectivity of future space communications systems.

G.1. Mobile Satellite (MSAT)

Since 1982, NASA has been working with the commercial communications industry to develop technologies for a mobile satellite system that would enable cost-effective communications with users in automobiles, ships, and aircraft anywhere in the satellite's area of coverage. The Mobile Satellite (MSAT) Program is a joint NASA-industry endeavor to accelerate the introduction of mobile satellite services in the U.S. and to develop the enabling technologies needed to ensure future growth. NASA will launch the first generation system, which is being built and paid for by industry. In exchange for launch services, NASA will retain a limited amount of channel capacity on the satellite to conduct government experiments.

G.2. Advanced Communications Technology Satellite (ACTS)

The goal of NASA's Communications program is to develop advanced communications satellite technology to support future telecommunications needs. The Advanced Communications Technology Satellite (ACTS), planned for launch in 1993, is a key element in NASA's communications program.

The NASA ACTS Program sponsors the development and flight testing of high-risk advanced communications satellite technology. The ACTS scanning spot-beam satellite provides qualitatively different communications capabilities compared with conventional satellites or terrestrial networks. The combination of high-gain multibeam antennas, producing fixed and scanning spot beams, and the baseband processor, which provides switching and message routing, permits unique communications performance in public and private networks.

In 1989, the ACTS Program Office defined a number of broad applications areas so that the resources of the Experiments Program may be focused and effectively exploited. These applications areas represent a maximum use of the ACTS technologies and include the following fields: video, mobile (including aeronautical, vehicular, and maritime), high data-rate, Integrated Services Digital Network (ISDN), public and private networks, NASA Science networks, and military applications.

G.3. Search and Rescue Satellite (SARSAT)

SARSAT program was initiated by NASA in the 1970's. The program in the United States is a joint venture that involves NASA, the National Oceanic and Atmospheric Administration (NOAA), the United States Coast Guard (USCG) and the United States Air Force (USAF). Internationally, the program is known as COSPAS-SARSAT. The space segment consists of two operational U.S. satellites, as well as two operational satellites provided by the USSR. Stations located in ten countries comprise the ground segment. Radio transmissions, from beacons used in emergency situations, are intercepted by the orbiting satellites that form the constellation and are redirected to the appropriate ground station for data processing. The critical information is relayed to the rescue coordination center. To date, the COSPAS-SARSAT program has been instrumental in saving over 1,400 lives.

G.4. Telemedicine

Telemedicine is the term given to the combination of electronic medical monitoring systems and communications. From the earliest days of manned space flight, NASA has developed and used telemetry to monitor the electrocardiograms and other vital signs of the astronauts during flight. Since 1971, modern health care systems have used much of the technology that was developed for space medical monitoring to provide routine patient consultation capability for physicians in remote areas or at small medical facilities, to demonstrate surgical and/or invasive procedures, and for continuing medical education activities. Telemedicine now augments existing health care delivery systems by providing a direct link between remote paramedic personnel working with the patient and experienced physicians at a central location.

Reliable physiological monitoring and communications permit a largely dispersed populous to benefit from a limited supply of highly trained personnel. The 1989 Armenia-US medical telebridge and the Ufa-Armenia-US hook-up became the first examples in history of the use of a system of satellite communications in support of systematic, long-term, multidisciplinary collaboration among the medical personnel of two nations.

V. THE SPACE EXPLORATION INITIATIVE (SEI)

In 1989, President Bush first spoke about the necessity to expand human activity into the solar system by returning to the Moon, establishing a permanent manned presence, and using that base as a stepping stone for the human exploration of Mars. The President's Space Exploration Initiative (SEI) responds to the fundamental human impulses to explore and acquire knowledge about ourselves and our surroundings. At the same time, SEI provides an opportunity for payoffs in the vital areas of economic competitiveness, educational excellence, quality of life, and international cooperation.

On February 16, 1990, President Bush approved the policy for SEI as an evolutionary approach comprising both Lunar and Mars program elements, as well as robotic science missions. The near-term focus is to be on technology development through a comprehensive search for new and innovative approaches; investment in innovative technologies with the potential to have a major impact on cost, schedule, and/or performance; and system analysis studies. Selection of a baseline program architecture will occur after several years of defining two or more reference architectures while developing and demonstrating broad technologies. NASA is to be the principal implementing agency, while the Departments of Defense and Energy will have major roles in technology development and concept definition. The National Space Council will coordinate the development of an implementation strategy by the three agencies.

The systems will be initially tested in Antarctica, as the dry valleys, mountains, and lakes found in that region provide the most Mars-like environment on Earth in terms of remoteness, terrain, temperature, and historical ecology. This "Antarctic Analog" will provide a unique testbed for the development of Mars and Lunar systems, including life support hardware, science equipment and activities, remote operations, automation and robotics, and human behavior and performance.

Initial SEI transportation centers around the use of a Heavy-Lift Launch Vehicle (HLLV) and the presence of Space Station *Freedom* as a staging platform. Robotic spacecraft will provide many integral functions, including the definition of landing sites.

International cooperation as a component of SEI will provide significant opportunities for both the U.S. and the international scientific community, including access to first-rate technical capabilities and a reduction in costs. Consequently, the President decided on March 30, 1990, that an exploratory dialogue should be opened with Europe, Canada, Japan, and the Soviet Union, and other nations as appropriate.

VI. SPACE TRACKING OPERATIONS

NASA's Office of Space Operations provides tracking, communications, and data acquisition services for a variety of spaceborne science missions and launch vehicles including Shuttle flights, solar system exploration, and Earth observation spacecraft which monitor weather and other atmospheric phenomena.

A. SPACE NETWORK: TRACKING AND DATA RELAY SATELLITE SYSTEM (TDRSS)

The baseline TDRSS, consisting of a constellation of three satellites and an Earth station, has been in full operation for the past two years. The three spacecraft operate in geosynchronous orbit, providing space tracking and communication links between user spacecraft in low-Earth orbits and the ground facility in White Sands, New Mexico. The ground facility itself is operated by CONTEL Federal Systems Division, Fairfax, Virginia, under contract to NASA.

TDRSS provides communications opportunities of up to 85 percent of the orbital period of low-Earth orbiting users as compared with approximately 15 percent coverage provided by the older ground-based tracking stations. TDRSS also provides significantly higher rates of data transmission.

A second back-up ground station is under construction and is slated to begin operations in 1993. Three additional spacecraft are also under construction for the augmentation and replenishment of the TDRSS constellation through the mid to late 1990's. The first of these spacecraft is scheduled for launch in the summer of 1991 on board Shuttle flight STS-43 (*Discovery*), and will replace TDRS-1, the first spacecraft of the series, launched in 1983, and nearing the end of its operational life.

B. ADVANCED TDRSS (ATDRSS)

ATDRSS Phase B contracts are nearing completion. Three participating companies are conducting design tradeoffs and demonstrating the technologies necessary to build the next generation of space network spacecraft and ground systems. The ATDRSS is intended to ensure continuation of the space network capabilities through the year 2012.

C. DEEP SPACE NETWORK TRACKING OF *MAGELLAN* AND *GALILEO*

Commands for controlling *Magellan* and *Galileo* are sent to the respective spacecraft through a single beam of radio signals from the antennae of NASA's Deep Space Network (DSN) Complexes. The *Galileo* command memory of 43,000 8-bit words can provide the spacecraft with enough instructions to carry out a sequence of tasks over a period ranging from days to months, depending on the complexity of the commands.

The DSN is in the process of retrieving data from both the *Magellan* and *Galileo* missions. The former continues to map the surface of Venus and return invaluable data, while the latter is not scheduled to arrive at Jupiter until December of 1995. Nevertheless, important data has been received through the DSN from *Galileo's* flybys of Venus and the Earth, as it passed these planetary bodies in order to benefit from gravity-assisted velocity boosts.

VII. SPACE RESEARCH TECHNOLOGY

A. SPACE RESEARCH AND TECHNOLOGY

The primary goal of the Space Research and Technology program is to develop advanced technologies that enhance and enable future United States space missions. In order to achieve this goal, a commitment has been made to conduct a broad-based research activity which constantly advances technology at the concept, subsystem, and system level; to develop technical strengths in the engineering disciplines within NASA, industry, and academia; and to perform critical flight experiments in areas where testing in the space environment is necessary for technology development. As such, the Space Research and Technology program directly supports the evolution of such initiatives as President Bush's Space Exploration Initiative (SEI).

Towards this effort, NASA will develop the technology, capability, and infrastructure to monitor and study our own Earth; second, to return to the Moon permanently with the establishment of a manned lunar research base; and third, to undertake a sustained set of manned exploration missions to the planet Mars. In addition to the manned exploration, a vigorous unmanned program to explore the solar system in detail with robotic explorers is to be pursued.

The Space Research and Technology program, designed to accomplish these national space goals, is divided into five "thrusts" of technology development: space transportation, Space Station, space science, exploration, and breakthrough. Additionally, a key element of the Space Research and Technology program is developing and sustaining a strong partnership with the university community. Thus the goal of the University Space Research program is to enhance and broaden the capabilities of the nation's engineering community through active participation in the U.S. civil space program. The program is an integral part of the strategy to improve the space research and technology capabilities of the United States.

A.1. Transportation

The transportation thrust of the program addresses those technologies which will serve to provide safer and more efficient access to space while reducing the overall costs associated with space launches. These technologies should serve to contribute to the effective design of a new fleet of space vehicles, including new expendable and partially-reusable cargo launch vehicles; fully-reusable manned vehicles; and both expendable and reusable space transfer vehicles. In some cases, they may also provide additional capability for existing launch vehicles.

A.2. Space Station

Research on the Space Station will help to provide applicable technologies for the current and evolutionary Space Station, including the technology base required for future developments for exploration. This thrust addresses those technologies that will serve to help expand capability while reducing life support costs of the initial Space Station *Freedom*; enhance its utility as a transportation node for the future Space Exploration Initiative; and improve Space Station capabilities as a testbed to conduct future technology development and validation studies.

A.3. Space Science

Space science efforts will help provide technology for programs focused primarily on the Earth, the solar system, and beyond. This approach supports the technology efforts necessary to expand capability and reduce costs through advances which can increase scientific information return and improve spacecraft performance while providing for the success of the next generation of space science missions.

A.4. Exploration

The objective of the exploration thrust is to develop the critical technologies required for future solar system exploration missions, including, but not limited to, establishment of a manned outpost on the Moon and human exploration of the planet Mars. This effort will develop a broad set of technologies that could serve to enable new and innovative capabilities, increase reliability for human missions beyond low-Earth orbit, reduce development and operations costs for long-term exploration efforts and enhance performance for both human and robotic missions.

A.5. Breakthrough

The emphasis on breakthrough technologies serves to explore those advanced concepts with the potential for major evolutionary advances. The focus of this thrust is to explore advanced high risk, high payoff technologies that have the potential to revolutionize the conduct of future programs.

The Space Research and Technology program is composed primarily of two complementary parts: the research and technology (R&T) base program, and the focused technology programs. The former serves as the seedbed for the development of new technologies and efforts to further enhance current capabilities. Through the R&T base program, scientists and engineers develop forecasts regarding the potential applicability, usefulness, and the overall benefit associated with new technologies. Once the potential of a new capability is documented, decisions are made on whether to transfer selective discoveries into focused technology.

Three focused programs have been initiated since 1988, the Civil Space Technology Initiative, the Exploration Technology Program (formerly called Pathfinder), and the In-Space Technology Experiments Program. In the focused programs, technologies are developed for specific applications, and products are delivered in the form of large-scale technology demonstrations, as well as demonstrated hardware, software, design techniques and methods. Focused development is most often initiated based on the identified needs and potential of both those current and future programs which have been identified as filling the needs of the technology thrusts.

B. RESEARCH AND TECHNOLOGY BASE

Significant accomplishments were achieved in 1990 in the R&T Base. Two examples of advances in transportation and Space Station-oriented technology programs are in the guidance and control, and the materials and structures areas. In support of future transportation requirements, and as an element of a future onboard ascent guidance system, the potential range of five different laser sensors was evaluated for use in light detection and ranging (LIDAR) wind sensors on launch vehicles. These laser sensors would provide data on the velocity of winds aloft and ahead of the vehicle. Using this information, adaptive guidance algorithms would compute structural load alleviation trajectories for safe passage of the vehicle to orbit. This approach expands the wind velocity envelope into which a vehicle could be successfully launched, providing greater operational efficiency, and a better on-time launch capability.

The *Long Duration Exposure Facility* (LDEF), which was retrieved by the Shuttle in January of 1990, after almost six years in low-Earth orbit, carried 57 technology experiments contributed by NASA centers, other federal laboratories, U.S. industry and universities, as well as foreign space agencies and universities. Over 10,000 specimens of construction, thermal protection, and solar cell materials are now being evaluated for their protective capabilities, while solar cell materials are being evaluated for their resistance to the corrosive effects of atomic oxygen and radiation. As a result of the extended time that the facility spent in orbit, it is also providing extremely valuable data on the number and size of meteoroid and space debris impacts. The LDEF data will enable the characterization of the environment that the Space Station will encounter during its planned lifetime, and will aid in the decision-making process on the choice of materials and construction, debris shielding, and other important factors.

Finally, a key element of the Space Research and Technology Program is developing and sustaining a strong partnership with the university community. The goal of the R&T Base University Space Research Program is to enhance and broaden

the capabilities of the nation's engineering community through active research participation in the U.S. civil space program. Nine centers selected in 1988 to participate in the University Space Engineering Research Center Program have already shown significant technical and educational benefits. For example, the Mars Mission Research Center at North Carolina State University and North Carolina A&T University is pursuing a joint research activity with the McDonnell Douglas Company for an in-space Mars aerobrake assembly. They will fabricate a mock aerobrake structure and assemble it in a neutral buoyancy tank. The University of Idaho Center for Space Engineering Research for Very Large Scale Integrated (VLSI) System Design is developing a compression/decompression VLSI chip for operational use as part of the Hubble Space Telescope ground data system.

This program has begun to offer valuable educational benefits, as well as attracting more graduate and undergraduate students to pursue aerospace careers, supporting new graduate level classes and introducing new material into undergraduate courses, and supporting cross-discipline and departmental thesis topics. This effort is an important contribution to broadening the nation's engineering capability to meet the critical, evolving needs of the civil space program.

C. CIVIL SPACE TECHNOLOGY INITIATIVE PROGRAM

Recognition of the need to expand and revitalize the U.S. civil space technology base led to the initiation of the Civil Space Technology Initiative (CSTI) in 1988. CSTI's primary focus is the development of technology to support efficient, reliable access to, and operations in, Earth orbit, and science missions conducted from Earth orbit. CSTI will develop specific technologies critical to the accomplishment of near-term, high priority national space goals.

In the transportation area, the main goal is to provide a significantly strengthened technology base for the design, development, management and operation of high performance, long-life propulsion systems, and to demonstrate aerobraking technology to support the design of future aeroassisted vehicles.

The area of operations is being addressed in a number of significant ways by the CSTI program. Artificial Intelligence is being developed and introduced into space transportation operations, science mission planning and execution, and to increase real-time decision making capability. Telerobotic capabilities are directed towards reducing the need for humans to perform dangerous, repetitive and boring tasks, and are being developed for in-space assembly, transportation servicing and in-space servicing activities.

Science technology requirements addressed by CSTI are concerned with space data acquisition, manipulation and management, both in orbit and on Earth. Particular emphasis is currently being placed on the development of increased sensitivity and spectral range for earth observing and astrophysical missions, on advanced mechanical cryogenic coolers with sufficient lifetime and capability for the next generation of science missions, and on advanced data processing capabilities to capture, process and archive the enormous volumes of data that will be generated by missions already planned.

During 1990, several exciting accomplishments were achieved. One example in the artificial intelligence area is the Spacecraft Health Automated Reasoning Prototype (SHARP), an expert system designed to monitor the condition of interplanetary spacecraft and ground operations. SHARP demonstrated a significant leap in automation technology during the difficult operational environment of *Voyager* mission operations during the encounter with Neptune. The SHARP system automatically confirmed that a problem existed in attempting to recover and process data from the *Voyager* transmissions. It then defined the magnitude and aided in the tracing the cause of the malfunction to a specific failed electronic unit on the ground which was then replaced. Using traditional methods, this process of identification and isolation would have been both laborious and time-consuming.

Also in 1990, a submillimeter wavelength backward wave oscillator (BWO) prototype was demonstrated. This enables the design of a high-frequency oscillator that is capable of significant power while being continuously tunable at submillimeter wavelengths. As a result, sensors can be developed in the use of very high frequency submillimeter wavelengths for the space spectroscopy required for space astrophysics, upper atmosphere remote sensing, and solar system exploration.

C. EXPLORATION TECHNOLOGY PROGRAM

The Exploration Technology program, which was started in the Fall of 1988 as the Pathfinder program, implements the President's National Space Policy directing that we begin to plan for future solar system exploration missions. The Exploration Technology program will develop the critical technologies that are required to enable missions that expand human presence and activity beyond Earth orbit into the solar system. On July 20, 1989, President Bush challenged the nation to set forth with a renewed commitment to exploration. This vision has been embodied in the Space Exploration Initiative.

The Exploration Technology program is a critical step supporting that Presidential directive by establishing a foundation of technology for these future missions of exploration. The Exploration Technology program, as a partnership

between NASA, industry and academia, will enhance our Nation's "cutting edge" in the highly competitive arena of aerospace technology. The Exploration Technology program is developing new technologies in several broad areas to enable future robotic and piloted solar system exploration: surface exploration, in-space operations, humans in space, space transfer, lunar and Mars science, information systems and automation, and nuclear propulsion.

During 1990, progress was made in a number of key areas. The Exploration Technology Program supports NASA's contribution to the ongoing space nuclear power research and development effort, the SP-100 Program. The program, a joint NASA, Department of Defense and Department of Energy endeavor, successfully completed key accelerated life testing of reactor fuel pin elements. With no appreciable swelling of the fuel pins, even after five percent fuel burn-up, the testing demonstrated that lifetimes of seven years should be achievable with SP-100 technology. This test was a critical step towards bringing this technology to maturity for application at a lunar outpost early next century.

Also in 1990, preliminary technology development in the sensors area of the Sample Acquisition, Analysis and Preservation Program (SASPP) occurred. In particular, a spectrometer breadboard for visible and near-infrared sensing which could be applied to sensor systems for early robotic Mars sampling missions was completed and demonstrated. Also, testing was conducted on rock coring techniques and parameters using a research robotics arm and drill fixture in a laboratory environment. Additionally, the Exploration Technology Program Planetary Rover effort completed fabrication and began testing of two experimental robot concepts: a multi-chassis, six-wheeled rover concept, and a six-legged walking rover concept. Both vehicles traveled over benign and rugged terrain as part of this testing phase. These experimental robots will form the foundation for continuing development of mobile robotics software and navigation technologies which will support future exploration of challenging - but scientifically intriguing - areas of the Moon and Mars.

In the area of human support in space, an innovative exercise facility was completed at the NASA Ames Research Center which will be used to study the human metabolic response to orbital extravehicular activity (EVA) work. The facility incorporates a controlled atmosphere chamber, an EVA work exercise device which duplicates upper body movements in zero-gravity conditions, human metabolic instrumentation to monitor blood pressure, body temperature, respiration rates, carbon dioxide and water expiration, and oxygen intake. Human metabolic responses to simulated EVA work will be obtained so that thermo-regulatory control methods may be designed to more accurately reflect the EVA work requirements resulting in increased astronaut comfort within a space suit, particularly for EVA missions approaching eight hours in duration.

Finally, NASA announced in November of 1990 that it had joined the Concurrent Supercomputing Consortium, a newly-formed group of research organizations that will tackle some of today's most demanding computational challenges. As a benefit of the agency's membership, NASA researchers will have access to the world's fastest supercomputer, the Touchstone DELTA system, when it becomes operational at the California Institute of Technology, next spring.

VIII. SPACE COMMERCE

There is increasing recognition, both in the United States and abroad, that space has attributes that are of great value. These resources and characteristics will play a major role in opening a new economic frontier for the spacefaring nations of the world. Current U.S. Government policy is that an expanded and aggressive private sector investment in space-related activities will generate economic benefits for the nation and for the governmental space sector by creating a wide range of new goods and services, and, moreover, that it will help to keep the United States on the cutting edge of space technology in an increasingly competitive international commercial space environment.

It is clear that commercial development of space is both a logical progression in the United States' civil space efforts and a prudent competitive strategy. NASA's Office of Commercial Programs (OCP), created in 1984, is the focal point for the agency's efforts to stimulate and assist expanded involvement and investment by the U.S. private sector in civil space activities. OCP also helps foster the commercial application of space technology.

Among the initiatives undertaken by OCP's Commercial Use of Space Program are sponsorship of sixteen non-profit Centers for the Commercial Development of Space (CCDS) - university, industry, and government consortia for high technology research and development with potential commercial applications and innovative working agreements that allow commercial users access to government facilities and expertise on a favorable reimbursement basis. OCP also fosters commercial interest in space by accelerating transfer and use of NASA-generated technology to private industry through its Technology Utilization Program. In addition, the Small Business Innovation Research (SBIR) Program is managed by OCP, seeking to involve small, innovative businesses in research that could lead to commercial space ventures.

A. COMMERCIAL DEVELOPMENT OF SPACE STRATEGIC PLANNING

True space commerce is achieved when industries are established that generate new products and services for specific private markets. Development of these new products and services will, in turn, support the growth of other commercial space industries, such as transportation and infrastructure. A major goal of NASA is to assist the private sector in the development of commercial space as a new sector of the national economy.

The Commercial Programs Advisory Committee (CPAC) was established to provide NASA with continuing advice on the proper roles and responsibilities of government and industry in the commercial development of space. CPAC is composed of corporate Chief Executive Officers and university presidents.

NASA initiated a new method of outreach to American business by sponsoring "Technology 2000," the first industrial exposition and conference to showcase the transfer of NASA technology to the private sector. Aimed primarily at non-aerospace business, Technology 2000 attracted more than 2400 people, and featured presentations by NASA and industry leaders who addressed prior and potential spinoffs of the agency's research.

B. COMMERCIAL USE OF THE SPACE PROGRAM

The development of new products and services, especially those involving materials processing or life sciences, requires long-term industry commitment. There are a number of barriers to this development (such as the high upfront cost of accessing space) which can be insurmountable for firms conducting research and development that may or may not yield returns until years in the future. NASA's Centers for the Commercial Development of Space (CCDS) Program is one of the mechanisms targeted towards overcoming these obstacles to market development.

The CCDS's, which form the cornerstone of NASA's assistance to private sector commercial space initiatives, are a network of 16 competitively-selected consortia of universities, industries, and other governmental organizations performing the early research and testing phases of potentially commercially viable technologies. Through a grant program, NASA provides the initial financial backing necessary for the applied technology phase, while academia and industry provide the market-driven approach required to bridge the gap between applied research and commercial application. This approach will ultimately result in large scale industry involvement in developing space-related technologies. These industry-driven technologies could, in turn, lead to a broad range of new markets and services.

The 16 CCDS's involve the active participation of 238 corporate organizations and 72 universities. Industry has demonstrated its commitment by investing heavily in this cooperative program. For example, the average ratio of industry matching funds (measured in cash and in-kind services) to government funding for the 16 CCDS's, is approximately 2.2 to 1. The ratio of just the first five CCDS's, established by NASA in 1985, has risen to 3.4 to 1.

C. COMMERCIAL DEVELOPMENT PAYLOADS

Commercial space flight activity in 1990 included six middeck experiments carried on the Space Shuttle, as well as the launch of *Consort 3* aboard a Starfire sounding rocket from White Sands Missile Range, New Mexico on 16 May. The half-ton *Consort* payload was carried to an altitude of 200 miles and provided approximately 7 minutes of microgravity for 12 experiments provided by the CCDS program. The flight was the third in the continuing sounding rocket campaign managed by the Consortium for Materials Development in Space, a CCDS member located at the University of Alabama-Huntsville.

Commercial experiment payloads flown aboard the Shuttle in 1990 include: a Protein Crystal Growth (PCG) experiment provided by the Center for Macromolecular Crystallography (CMC) at the University of Alabama-Birmingham, carried aboard STS-32 in January; a Fluids Experiment Apparatus (FEA) flown on STS-32 under a NASA-Rockwell International Corporation joint endeavor in the field of floating crystal growth and purification research; a second flight of the PCG on STS-31 for CMC; an Investigations into Polymer Membrane Processing (IPMP) experiment developed by the Battelle Advanced Materials Center in Columbus, Ohio; a Physiological Systems Experiment flown on STS-41 for the Center for Cell Research at Pennsylvania State University and its industry affiliate, Genentech, Inc.; and a second flight of the IPMP experiment on STS-41.

In order to support its increasing commercial flight payload requirements, OCP is sponsoring the development of the *Commercial Experiment Transporter* (COMET), a system for launching and recovering commercial spaceborne experiments. Carried aloft by an expendable launch vehicle, the COMET free-flyer will contain both a service module and a recovery system. The two components will separate prior to reentering the atmosphere so that others, not requiring retrieval, can continue their mission aboard the service module. Current plans call for mid-1991 launch of the new system into equatorial orbit.

Additionally, in order to expand private sector experiment capability aboard the Space Shuttle, NASA has awarded a contract to Spacehab, Inc. for a Commercial Middeck Augmentation Module. This commercially-developed and owned module will ride in the Shuttle bay, be accessible through the airlock, and will add the volume equivalent of about fifty middeck lockers to the orbiters' capacity.

D. TECHNOLOGY DEVELOPMENT

Sixty-one new technologies have been defined by the CCDS program, many of which are expected to mature as economically useful applications. Extensive ground tests have proven the need for further flight testing of these technologies. Since the inception of the CCDS Program, the following experiments have been completed toward technology development: 1,089 drop tube/drop tower experiments; 81 Lear/KC-135 flights, 19 payload flight tests aboard 3 sounding rockets; and 10 flight tests aboard the Space Shuttle.

E. COOPERATIVE AGREEMENTS

The cooperative agreements administered through OCP during 1990 represent another facet of government/industry cooperation in the commercial development of space. For example, an agreement was finalized between NASA and Orbital Sciences Corp., in support of the firm's commercial launch vehicle programs, through which NASA will provide, on a cost-reimbursable basis, access to agency launch support property and services.

In addition, a memorandum of understanding was signed between NASA and the Technical and Administrative Services Corps., which provides a forum for the exchange of research information associated with closed environment systems related to food production both on Earth and in space.

F. TECHNOLOGY UTILIZATION PROGRAM

The technology which NASA develops to meet its research and program goals represents an important national resource. The NASA Technology Utilization Program seeks to encourage greater use of America's technology storehouse by providing a link between the technology and those who might be able to put it to advantageous use. The aim is to accelerate and broaden the technology transfer process, and thus expand the benefits to the nation. NASA, through this long-standing program, has maintained a systematic approach for identifying space technologies which may have useful application in the non-space sector of the economy.

The Technology Utilization Program involves both technology dissemination and technology application. Technology dissemination requires the identification and gathering of information on aerospace technologies making this information available

to the private sector. Technology application is the use of these NASA technologies in specific projects for public benefit.

Tne 1990 edition of NASA's annual *Spinoff* magazine documented spinoff products resulting from secondary applications of NASA-developed technology in such areas as public safety, the environment, medicine, consumer/home/recreation, computer technology, and industrial productivity. Over the years, NASA-derived technology has been the basis of more than 30,000 spinoffs. The process of developing and marketing spinoffs based on NASA technology has had a dramatic effect on the American economy, fostering great strides in aeronautics, computers, medicine, and other areas.

G. SMALL BUSINESS INNOVATION RESEARCH PROGRAM

The Office of Commercial Programs (OCP) is responsible for the Small Business Innovation Research (SBIR) Program, which plays an important role in the former's commercial development program. SBIR Program objectives, established by law, include stimulating technological innovation in the private sector, strengthening the role of small businesses in federal R&D programs, fostering and encouraging greater participation of minority and disadvantaged businesses in technological innovation, and increasing private sector commercial development of innovations derived from federal research and development.

In 1990, SBIR awarded 280 Phase I and 84 Phase 2 contracts to small, high technology firms. Additional Phase 2 awards, to be made in 1991, are expected to bring the total number of selections to more than 120.

IX. INTERNATIONAL SPACE YEAR (ISY)

The 1992 International Space Year (ISY) has won unanimous support from national and international organizations and has been a catalyst for facilitating and implementing several significant international applications of research programs and educational activities. NASA, as directed by Presidents Reagan and Bush, leads the U.S. ISY effort, and has been an active participant, both nationally and internationally, in planning for 1992.

NASA led efforts to establish a Space Agency Forum on the ISY (SAFISY) to better coordinate, plan, and optimize the resources of the world's space organizations. SAFISY selected Mission to Planet Earth as a key theme for the ISY, and a Panel of Experts on Earth Science and Technology was established to identify international Earth science cooperative research projects that could be implemented as part of ISY activity. The Panel's second meeting was held in Austria in February of 1990 to review the status and progress of activities currently underway. NASA contributes to all twelve projects currently under the auspices of the Panel, and leads two other projects: (1) Greenhouse Effect Detection, and (2) Polar Stratospheric Ozone.

A second SAFISY panel, the Panel of Experts on Education and Applications, was established to emphasize training and space education, and is chaired jointly by the French Space Agency (CNES) and NASA. This panel met in France during February of 1990 with the purpose of identifying and defining proposals in two areas: (1) Training and Remote Sensing Applications (chaired by CNES), and (2) Space and Education (chaired by NASA). Forty proposals were identified at this meeting and brought forward to the May 1990 full SAFISY meeting held in Kyoto, Japan.

At NASA's request, a third SAFISY international panel of experts was convened to focus on space science, specifically in areas other than solar-terrestrial and Earth science. SAFISY invited the Committee on Space Research (COSPAR) of the International Council of Scientific Unions (ICSU) to take the lead in forming such a panel. The first formal meeting of the SAFISY Panel of Experts in Space Science was held at the Hague, Netherlands, on the occasion of the twenty-eighth COSPAR Plenary, held during mid-1990, followed by a second Panel meeting on December 7 and 8, 1990.

In addition to NASA's role in SAFISY, a U.S. contribution to the United Nations/ISY activities was initiated by NASA and proposed to the United Nations Outer Space Affairs Division, Space Applications Programme, as a joint effort with the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Geological Survey (USGS). This contribution is aimed at promoting developing countries' use of remote-sensing data for resource management and global change

studies. The U.S. contribution will consist of three activities, including an international training course (*Remote Sensing Applications for Environmental Assessment and Monitoring* September-October, 1991), an international conference (*Satellite Remote Sensing for Resource Management, Environmental Assessment and Global Change Studies: Needs and Applications of Developing Countries* April-May, 1992), and an international workshop on strategies for developing an international data exchange network through the United Nations Environmental Programme (UNEP) Global Resources Information Database (GRID), which will be held May 4-6, 1992, immediately following the international conference.

NASA also chairs an ISY Interagency Working Group and its Subcommittee on Education. This group is chartered to promote U.S. national activities related to the ISY, and to serve as a liaison between the U.S. government and the private sector regarding the ISY. During 1990, the group convened to review the status of member plans for ISY and new projects. Group membership reflects representation from government agencies, private corporations, and educational organizations.

During 1990, the U.S./ISY Association, through support from NASA, continued to promote U.S. private sector and public ISY activities. Through press releases, conferences, and meetings, the U.S./ISY Association disseminated information on the coming International Space Year, and promoted the establishment of public activities such as films and television, exhibits, student and teacher activities, and conferences. In 1990, the U.S./ISY Association facilitated the establishment of a counterpart in Europe: the European/ISY Association (EURISY).

X. SPACE RESEARCH OPPORTUNITIES

A. ANNOUNCEMENTS OF OPPORTUNITY

It has historically been United States policy to make virtually all civil spacecraft projects, whether flight or ground-based, open to domestic and foreign scientific participation on an equitable and cooperative basis. Foreign proposals received in response to research announcements by the NASA International Affairs Division will go through the same evaluation and selection process as proposals originating in the United States. In the case where a foreign proposal is selected, NASA will consequently arrange with the sponsoring foreign agency for the proposed participation to be on a cooperative (no exchange of funds) basis, in which NASA and the sponsoring agency will each bear the cost of discharging their respective responsibilities.

B. EXPERIMENTS WITH FOREIGN INVESTIGATORS

Foreign scientists, working in their own laboratories, may participate in NASA cooperative space missions as Principal or Co-Investigators through the provision of scientific experimental hardware, the analysis of relevant mission or supporting data, or both. The participation of such Principal Investigators is noted in the sections concerning individual projects.

C. SCIENTIFIC AND TECHNICAL INFORMATION EXCHANGE

NASA has scientific and technical information (STI) document exchange agreements with some 220 organizations in 43 countries.

Under a special arrangement with the Information Retrieval Service (IRS) of the European Space Agency, NASA makes its Scientific and Technical Aerospace Reports (STAR) and International Aerospace Abstracts (IAA) files of worldwide aerospace research available to the IRS. Qualified European organizations which have completed the proper agreement with NASA and the IRS have on-line access to these files in exchange for the submission of technical reports. The NASA Scientific and Technical Information Program has similar exchange agreements set up with the Australian Defense Information Services, Canada Institute for Scientific and Technical Information, and the Israel Space Agency. There are also proposed agreements being

worked on with the National Space Development Agency of Japan and the Hungarian Academy of Sciences.

D. EDUCATION

In 1990, NASA adopted the National Education Goals set by the President and the Governors as fundamental guidelines for developing and conducting education programs. As a result, a ten-year plan is being developed. Additionally, NASA and the Department of Energy (DOE) announced a memorandum of understanding to collaborate on education programs to help improve the nation's science, engineering, and math programs.

Astronauts presented the first live lesson from space on December 7, 1990, during the STS-35 ASTRO-1 mission. "Space Classroom, Assignment: The Stars," focused on the electromagnetic spectrum and its relationship to the high-energy astronomy mission. Following the crew presentation, Karen Weidenhofer, a teacher, conducted a one-hour follow-up lecture. The lesson concluded with Mission Specialists answering questions from 12 students in a classroom at Marshall Space Flight Center and 28 students in a control room at Goddard Space Flight Center.

Over four million students planted gardens during the spring to experiment with tomato seeds flown in space. Students grew and observed space-exposed seeds and Earth-based seeds, searching for differences caused by the long-term effects of radiation exposure. The Space Exposed Experiment Developed for Students (SEEDS) was one of 57 experiments housed on the LDEF satellite. NASA distributed over 132,000 kits to approximately 64,000 teachers.

In 1990, 21 designated Space Grant Colleges/Consortia were selected following NASA's National Space Grant College and Fellowship Program. In an effort to expand the program, Phase II was announced in May of 1990, offering institutions in the remaining 29 states and the District of Columbia an opportunity to compete for Program Grants or Capability Enhancement Grants.

In a new education initiative, the Teacher Training Pre-Service Program, research grants were awarded to two universities to develop teacher training courses that will enable teachers to incorporate aerospace topics and concepts into their classrooms and to create new and imaginative practices in learning.

In March, NASA debuted the first of what will be a small fleet of tractor-trailer mounted mobile teacher resource centers that will travel the nation providing lesson materials to teachers who could not otherwise travel to a NASA field center. The

mobile center project is part of a larger education initiative, project LASER (Learning About Science, Engineering and Research).

During the summer of 1990, educators spent two weeks at one of NASA's nine field centers learning the latest in aerospace science and working with educational specialists to fit materials into a classroom curriculum. There were 115 elementary school teachers participating in NASA's Educational Workshop for Elementary School Teachers, and 100 participating in NASA's Educational Workshops for High School Math and Science Teachers.

Over 120,000 educators in the 50 states and Canada tuned in for NASA's satellite video conferences for educators. NASA projects covered in the live, interactive program this year included the Mission to Planet Earth program. ASTRO-1 mission, SEEDS, and robotics in space.

Under NASA's Graduate Student Researcher's Program, over $10 million was awarded to 523 students at approximately 150 universities for advanced students in engineering, space, physical, life, and environmental sciences. Continuing its efforts to encourage the next generation of scientists and engineers, NASA selected 37 graduate students at U.S. universities to take part in the new Global Change Fellowship Program. Students will conduct research in atmospheric physics and chemistry, biochemistry, ecosystems, hydrology, and oceanography, receiving $22,000 beginning in the 1990-91 academic year.

Postdoctoral and senior postdoctoral grants are available to qualified non-U.S. scientists for participation in research at NASA centers, NOAA laboratories, and NASA's Jet Propulsion Laboratory. The principal international exchange activity conducted by NASA is the Resident Research Associateship program, administered for NASA by the National Academy of Sciences. This program provides for post-doctoral research for one year at NASA installations in the scientific fields of astronomy and astrophysics. In addition, NASA provides technical training for foreign scientists and technicians in support of agreed upon cooperative programs.

E. VISITS AT NASA AND NOAA FACILITIES

Numerous officials and scientists from around the world visit NASA and NOAA installations each year for general orientation or information exchanges on space programs and related research. Also, a substantial number of foreign visitors are frequently invited to attend launchings.

F. INTERNATIONAL SUMMER STUDENT PROGRAMS

The International Summer Student Program is designed to encourage youths from other countries to pursue careers in aeronautics and space activities by offering opportunities for foreign students to work at NASA field centers during the summer months. The program began in 1983, and has had student participants from Australia, Brazil, Canada, Chile, the FRG, India, Indonesia, Italy, Japan, Mexico, Morocco, New Zealand, Senegal, Spain, the United Kingdom, the Gambia, and Norway.